energies

Special Issue Reprint

Challenges and Research Trends of Energy Business and Management

Edited by
Bernard Ziębicki and Edyta Bielińska-Dusza

mdpi.com/journal/energies

MDPI

Challenges and Research Trends of Energy Business and Management

Challenges and Research Trends of Energy Business and Management

Editors

Bernard Ziębicki
Edyta Bielińska-Dusza

MDPI
Basel • Beijing • Wuhan • Barcelona • Belgrade • Novi Sad • Cluj • Manchester

Editors
Bernard Ziębicki
Department of Management and Organization Methods
Cracow University of Economics
Krakow
Poland

Edyta Bielińska-Dusza
Department of Strategic Analysis
Cracow University of Economics
Krakow
Poland

Editorial Office
MDPI
St. Alban-Anlage 66
4052 Basel, Switzerland

This is a reprint of articles from the Special Issue published online in the open access journal *Energies* (ISSN 1996-1073) (available at: https://www.mdpi.com/journal/energies/special_issues/Energy_Business_and_Management).

For citation purposes, cite each article independently as indicated on the article page online and as indicated below:

Lastname, A.A.; Lastname, B.B. Article Title. *Journal Name* **Year**, *Volume Number*, Page Range.

ISBN 978-3-0365-9604-4 (Hbk)
ISBN 978-3-0365-9605-1 (PDF)
doi.org/10.3390/books978-3-0365-9605-1

Contents

About the Editors

Bernard Ziębicki

Dr. and Associate Professor at the Krakow University of Economics, Dean of the College of Management and Quality Sciences, head of the Department of Organization and Management Methods, member of the Committee on Organization and Management Sciences of the Polish Academy of Sciences, editor of the scientific quarterly *Organization and Management*, editor of the scientific bimonthly *Cracow Review Economics and Management*, and author and co-author of over 200 scientific publications in the form of monographs, articles, and conference materials on the following issues: organization and management methods, new management concepts, organizational effectiveness, and information management.

Edyta Bielińska-Dusza

Ph.D. in economics in the field of management science. Assistant Professor in the Dept. of Strategic Analysis of the Cracow University of Economics. Director of postgraduate studies in the "MBA in Community Management" program at the Cracow Business School of the Cracow University of Economics. Her research revolves around strategy, technology, artificial intelligence, innovation, digitalization, internal audit, and inter-organizational phenomena. She leads the project "The transformative impact of artificial intelligence on replacing people in innovation processes in the research and development activities of Life Science companies," which has financial support from the National Science Centre. Her lectures are dedicated to strategy management, technology audit, and technology design and forecasting, including management methods and tools. She has been a co-organizer of scientific conferences. She has served as an expert in various projects ("Revolution 4.0. Regional Initiative of Excellence", "Innovation Brokers as a tool for effective development", "First Business - Support to start", and "The Rapid Response Instrument"). She has also participated in study visits and scientific workshops (Stanford University and the University of Berkeley) and has various certificates (École Polytechnique Fédérale de Lausanne, Switzerland; ISIS Innovation Ltd, Oxford; Strategic Business Insights, Stanford; PRINCE 1&2).

energies

MDPI

Article

Barriers and Drivers for Changes in Circular Business Models in a Textile Recycling Sector: Results of Qualitative Empirical Research

Anna Wójcik-Karpacz [1], Jarosław Karpacz [1], Piotr Brzeziński [1], Anna Pietruszka-Ortyl [2] and Bernard Ziębicki [3,*]

[1] Faculty of Law and Social Science, Jan Kochanowski University of Kielce, 25369 Kielce, Poland
[2] Department of Organizational Behavior, Cracow University of Economics, 31510 Kraków, Poland
[3] Department of Organization and Management Methods, Cracow University of Economics, 31510 Kraków, Poland
* Correspondence: ziebicki@uek.krakow.pl

Abstract: The growing environmental problems associated with the dumping of large amounts of textile waste and the demand for circular products are prompting textile waste recycling enterprises to develop circular business models (CBMs). This implies a radical change in the way some enterprises operate to obtain growth. Considering the importance of the drivers of and barriers for the adoption and implementation of CBMs in the textile recycling sector, it is claimed that the comprehension of these factors to CBMs is limited and deserves more attention in empirical research. Therefore, our research investigates the antecedents of circular business models in the textile recycling sector by highlighting influencing factors. The aim of the article is to explore the main enhancing and inhibiting factors in the development of circular business models on the example of a large enterprise operating for 30 years in the textile recycling sector. In this study, a case study design of mixed methods, including semi-structured interviews with a business practitioner and the data presented on the websites of the surveyed enterprise, is used. The results suggest that main enhancing factors are relevant regulations at the European level, appropriate technologies and digitisation, and increasing social and environmental awareness of consumers and managerial capabilities. However, inhibiting factors are supply chain complexity and supply chain collaboration in connection with a large scale of business in crisis situations, a large scope and range of geographic diversification of outlets in the perspective of the consequences of the information gap, and readiness to take the so-called "being the first in the market" risk. In practice, this means that general drivers of the CBMs may facilitate the reuse of second-hand clothing and recycling of textiles for other new products as the primary CE action. On the other hand, enterprises have to overcome a number of technological barriers, and in the case of the textile recycling sector, it is necessary to understand which barriers they face to take appropriate actions. Research findings indicate factors that may be the subject of intervention or support of managers or policymakers. This study has practical implications and suggests future study paths.

Keywords: circular business model; circular economy; environmental awareness; supply chain; development; waste

Citation: Wójcik-Karpacz, A.; Karpacz, J.; Brzeziński, P.; Pietruszka-Ortyl, A.; Ziębicki, B. Barriers and Drivers for Changes in Circular Business Models in a Textile Recycling Sector: Results of Qualitative Empirical Research. *Energies* **2023**, *16*, 490. https://doi.org/10.3390/en16010490

Academic Editor: Krushna Mahapatra

Received: 7 December 2022
Revised: 23 December 2022
Accepted: 30 December 2022
Published: 2 January 2023

1. Introduction

The textiles and apparel manufacturing industry in the upstream fashion supply chain generates substantial materials waste which requires urgent efforts to manage effectively, reduce environmental impact, and foster sustainable practices [1,2]. Textile waste consists of industrial /pre-consumer waste and post-consumer waste. Industrial waste is generated by a production process and post-consumer waste, i.e., textiles thrown away (i.e., used clothes)—after the end of their service life [3,4]. For the specificity of the sector studied (i.e., textile recycling sector), an important area that should be taken into account is textile waste management, as today's clothes are designed for shorter use [5] and then utilised. It was estimated in various studies that only 20% of textile waste is recycled or reused, and the remaining 80% is landfilled or incinerated, which causes large losses of raw materials, energy, and has a negative impact on the environment [6–8].

Such a low level of recycling of post-consumer textile waste results from the conclusion that recycling and (more broadly) CBMs are strongly related to the existence of efficient and economically justified technologies. Recycling of multi-material products [2] is much more complicated (and generates significantly higher investment and operating costs of such technology) than the recycling of products made from a single material. This results from both the level of complication and the possibility of ensuring sufficiently large volumes of waste material which meets material specification. For example, the recycling of packaging bags made mostly of homogeneous polyolefins such as PE (PE HD, etc.) meets both conditions of a relatively cheap technology (mono-material with a significant amount of a given waste material). For the post-consumer textile sector being under consideration, the morphology of second-hand clothing is an important issue. Different types of clothes are recycled. Extremely different morphology of materials is used in their production (from a huge variety of synthetic and natural fibre, using various types of braids and fibre mixes, to a wide range of chemical additives and dyes). Clothing manufacturers, by introducing new clothes every new season (or for fast-fashion, even several times during one season), make sure that they differ visually from the ones already existing on the market, contribute unknowingly to further complicate the situation with regard to generated waste recycling.

That is why, recycling of post-consumer textile waste requires much more advanced (and most desirable in the CE model) technologies with a higher level of technological risk approach than the classic one based on separation and recovery of raw materials in order to create new things. This implies changes in existing business models toward higher levels of circularity.

Nevertheless, the barriers which enterprises face before implementing CBM [9] may delay the transition to a sustainable future [10], it is necessary to identify what prevents or delays the implementation of circular activities in organisations operating in the textile recycling sector. It is equally important to identify factors which may influence the successful development of CBMs. Especially since CBM has yet been widely implemented not only in the textile recycling sector, but also in the fashion sector [11].

That is why, the following research questions (RQ) were posed:

RQ1: What are the main drivers for the development of circular business models in the textile recycling sector?

RQ2: What are the main barriers to the development of circular business models in the textile recycling sector?

These two research questions guided our empirical research. At the same time, it was found important to understand these factors from the perspective of business practitioner being an important stakeholder in the transformation towards CE [12].

The aim of the article is to explore the main enhancing and inhibiting factors in the development of circular business models on the example of a large enterprise operating for 30 years in the textile recycling sector. This indicates that the article refers to specific challenges faced by enterprises belonging to the textile recycling sector by answering the above-mentioned research question.

The paper is structured as follows. The following section provides an overview of CBMs conceptualisation which also allows different types of CBMs to be identified. In addition, it sheds light on the issue of the legitimacy of continuing research about factors enhancing and inhibiting changes in circular business models in the textile recycling sector. Next, the case study with sections on research methodology, data collection from the VTR's websites and the primary data from semi-structured interviews with an enterprise representative are presented. In Section 4, the results of the analysis of primary and secondary data are described, while Section 5 focuses on the discussion of drivers and barriers to CBMs. Section 6 contains conclusions and implications for practice based on our research findings. The article ends with an indication of research limitations and suggestions for future research.

2. Literature Review

2.1. What Is the Circular Business Models?

Circular business models are essential elements of a circular economy framework to enable economically viable recapturing of value [13]. Circular business models (CBMs) describe the ways in which an organisation creates, delivers and captures values, while keeping resources at the highest level and for as long as possible [14,15]. In addition, this indicates that enterprises should think about what to do to keep their values (resources) as long as possible. This problem applies not only to textile waste management, but to production management from the very beginning: the first stage of production, predicting what would happen with our product at the end of its life. According to Wrålsen et al. [13], CBMs intend to maintain the maximum value of resources by eliminating or reducing its leakage through closing, slowing, or narrowing their flows. Moreover, Bocken et al. [16] explains that CBMs includes and aligns an enterprise value proposition with the creation, delivery, and capturing of value. Hultberg and Pal [11], in turn, conceptualise CBMs in another way. He argues that circular business model (CBMs) are terms used to describe business models based on circular economy practices. The literature studies also confirm the usefulness of this conceptualisation of the CBM construct. In the study by Lüdeke-Freund et al. [17], six different types of CBMs have been identified which support resource flows (referred to as "major CBM patterns"); these are: repair and maintenance; reuse and redistribution; refurbishment and remanufacturing; recycling; cascading and repurposing; and organic feedstock. A review of current circular practices in the vehicle industry in the EU reveals that several manufacturers implement CE strategies, focusing on CBMs for LIBs (lithium-ion batteries), and these are: intensify use; repair; refurbish; remanufacture; repurpose; and recycling [18]. However, in the studies by Lieder and Rashid [19], Akter et al. [1], Rahman et al. [2] and Mostaghela and Chirumallab [5], three different types of CBMs were identified, distinguished as: 3Rs: Reduce, Reuse and Recycle.

The results of the studies presented above provide a picture of the current circular practices and indicate the possibility of different operationalisations of CBMs in business practice, but also some similarities between them. There is no doubt that each industry has its own specificity, requiring adjustment of activities to products or services offered by an enterprise, and this generates various circular business models. Because of the fact that there is no waste in a purely circular economy, everything is looped back in different resource flows [20]. Within these loops, a large variety of CBMs emerge (i.e., distinguished above as "3R" and "6R"); while some cover the entire resource flow, others only focus on a specific activity and need to connect to other CBMs to create a complete loop [20].

Therefore, circular economy business models (circular business models) are a real alternative to the current linear systems of production and consumption [21]. "R-activities" are typical activities for circular business models, but do not appear in traditional linear models. CBMs help to reconcile resource efficiency with the creation of commercial value, using both environmental and economic values embedded in products [21]. The business advantage in the circular model is that enterprises use the idea of a circular economy to create values. In addition to resource efficiency, enterprises may also create economically significant products rather than waste. They may create resources for other market players or design a closed resource flow for their own business. This business model is in line with the principle of manufacturer's extended responsibility. The manufacturer's responsibility for a product is extended to the end of its life cycle [21]. Thus, these types of business models may significantly reduce the negative impact on the environment [22] if actively designed for this purpose [23,24]. However, the shift from a linear to a circular business model is an ambitious undertaking which requires a re-evaluation of how a given organisation creates, acquires and delivers values. Enterprise's values (goals), strategy and business opportunities already motivate enterprises to explore CE-based value proposition and develop circular business models (CBMs) [16]. Thanks to circular business models, enterprises gain a competitive advantage, increase customer loyalty to the brand, meet waste requirements more easily, and improve production towards zero waste [25]. Therefore, these BMs are facilitators and provide a framework for enterprises to create and capture values [26,27].

2.2. Circular Business Models in a Textile Recycling Sector: Influencing Factors

Textile recycling industry is one of those industries which may benefit economically from efforts for CE. Enterprises belonging to this sector, by thinking more specifically about promoting sustainable development, may want to get involved in CBMs. These organisations would strive to minimise the negative impact on the environment, striving to extend the life cycle of "industry/pre-consumer waste" and/or "post-consumer waste" from the phase of obtaining this waste to its disposal. In addition, especially since the global amount of textile waste will increase by 60% each year from 2022 to 2030, generating an additional 57 million tons of waste per year and reaching a total of 148 million tons per year (see more: [1,8,28,29]). Moreover, textile waste causes a potentially huge loss of value and business opportunities in a textile and clothing production chain [1].

That is why, Payne [30] and Jamshaid et al. [4] argue, among others, that solid waste should be recycled or reused to strengthen the concept of a circular economy. There is no doubt that wearing clothes for longer periods of time and efficiently using textile waste may significantly reduce the need for end products and fibres [4].

The aforementioned potentially huge increase in textile waste and the demand for circular products in the near future would make the circular economy (CE) more and more visible in business organisations [22,31]. Thus, in the textile recycling industry is an important category to discuss CE and CBMs. However, despite the general interest of a private sector in CE, implementation of CBMs is in fact still low in this sector [6–8].

In the context of the possibility of managing second-hand clothing, circular reuse business models (CBMs) have emerged in recent years, also in Poland (e.g., [32]), aimed at slowing down or closing resource cycles [33]. This shows that the transition to CE today requires radically new ways to design and implement business models, including the textile recycling industry. Most enterprises are concerned with transforming existing innovative linear economy processes, characterised by significant experimentation towards an ambitious circular value creation goal [33]. Nevertheless, there are some controversies over what may and what may not be considered as recycling. This includes (non-) treating energy recovery or production of fuels from textile waste as recycling. There are different interpretations and procedures on this issue, which raises a lot of controversy and discrepancies even in the recycling statistics. It is worth adding that European [34] and national [35] regulations directly exclude energy recovery and production of fuels from textile waste from the definition of recycling. It is worth emphasising that in Poland it is VTR that is very much involved in striving to improve the existing CBMs towards more sustainable CBMs (e.g., [36]) and this does not mean that there are no other enterprises which have already undertaken some steps in this direction; but we do not know much about them at the moment.

The literature research indicates that proper business models (BMs) are essential for enterprises to make the reuse of second-hand clothing and textile waste recycling economically feasible and require constant improvement and adaptation [37]. Thus, in order to improve BMs, the drivers for CBMs need to be strengthened to reach higher levels of circularity (i.e., [38–40]). Apart from that, in order to continue the process of change towards a more circular economy, the current barriers to the development of CBMs need to be addressed (i.e., [10,20,41–43]). Despite these valuable contributions to the scientific literature on drivers and barriers to implementing different circular business models, there are also many limitations to the research findings. Drivers and barriers differ depending on the sector and type of business model [10,43–45]. Therefore, there is shortage of knowledge about factors enhancing and inhibiting changes in circular business models in the textile recycling sector. Moreover, Ferasso et al. [22] emphasises that there is currently no unified understanding of the current state of knowledge about circular business models, as many studies have been published in a short time, their structures and discourses are not well established and interconnected. It is not clear which lines of research into circular business models are well developed and potentially saturated, and which deserve more attention in future studies.

3. Research Methodology

3.1. Research Design

Case study is an effective type of studies for gaining an in-depth understanding of the factors influencing changes of business models in the enterprise mentioned below [18]. Moreover, it represents a unique, credible, and valuable justification for the formulation of guidance for managers. It was decided to include one case because single case studies i.e., [46–48] are well established in the area of BMs [44]. The case was selected on the basis of a deliberate sampling [18].

The enterprise was chosen because it has more than one circular business model which it is actively trying to rethink. It is a business organisation which implements CE strategies, focusing mainly on the resale, re-purpose and recycling of second-hand clothing into textile composites. At the same time, VTR is one of the world's largest producers of second-hand clothing. In the enterprise's on-line store, one may order wholesale, directly from the manufacturer, i.e., VTR, sorted and top-quality second-hand clothing from the Western Europe. For 30 years, VTR has been developing its competences in this area, among other things. Currently, every day, it segregates textile waste in the amount of hundreds of tons, using the most modern in Poland and fully computerised lines for sorting clothes, enabling the processing of 500 tons of raw material per day while maintaining the highest quality standards, namely ISO 9001 and 14001. Every day, the VTR's employees sort and pack finished products from 700 different assortment groups. Moreover, the geographic diversification of sales markets is very large. Products (second-hand clothing) go to over 70 countries around the world and to a chain of several dozen VIVE Profit stores all over Poland, owned by VIVE Textile Recycling (e.g., [36]). Moreover, closed processes of recycling textile into innovative textile composites have long reached the commercial stage. The raw material which does not comply with the VTR's quality requirements is, in turn, processed into industrial cleaning products. VTR also produces industrial cleaning products used by enterprises from many industries (e.g., [32]). All of this makes VTR an interesting case to study.

The study used a mixed-method case study design [33,49], including semi-structured interviews with an enterprise representative and data presented on the VIVE Textile Recycling's (VTR) websites. Thus, complementary methods were used. The basic method was a semi-structured interview, and the subordinate method was an analysis of the data posted on the above-mentioned websites. Both methods were implemented several times to triangulate the data (e.g., due to outdated reports, official documents, end-user reviews, or respondent availability—in the case of semi-structured interviews). The triangulation of the methods in this study was parallel (complementary). Qualitative data were collected simultaneously and analysed to answer research questions.

Firstly, a literature review was conducted, interview guides were developed, and semi-structured interviews (see: Appendix A, Table A1) were carried out with a professional implementing CBMs at a textile recycling enterprise.

The purpose of the analysis of the empirical material was to search for answers to identify the main enhancing and inhibiting factors for business experiments towards a more circular economy, as well as actions which are aligned with circular economy.

The process of data analysis obtained in the interviews was carried out in three stages: (1) coding, (2) searching for similarities and differences, (3) interpretation. However, the preliminary analytical stage was the transcription of audio recordings (see: part 3.2. Data collection). Data in a written form were encoded, and the individual fragments were given appropriate labels for the categories under consideration (a priori, deductive coding). Collections of data with identical labels were subjected to a comparative analysis in order to capture similarities and possible repeating regularities. In the analytical process, the semantics of statements in the context of the studied categories were verified. The last stage of data analysis was the interpretation of the content of the interviews. Descriptions of individual aspects were presented in the form of narratives with references to directly quoted fragments of the respondent's statements collected during the interviews (abbreviated respondent's statements are presented in Part 4. Results and analysis; while selected full statements made by the respondent are in Appendix A, Table A2). As a result of the semi-structured interview, a summary of the main influencing factors for changes in CBMs in VTR was developed and "R-activities" were identified. The interview guides mentioned above, in turn, result from the literature review.

Secondly, data presented on enterprise's websites (e.g., reports, official documents, interviews with various enterprise's representatives) or other data (e.g., press releases, end-user reviews) were reviewed in parallel to better understand R-activities as well as external and internal forces which may accelerate or delay the achievement of higher levels of circularity by VTR. The result of this research method is the exemplification of VTR's circular activities, business achievements and relevant regulations. A flowchart summarises the research methods used and the outputs of each one of them, as shown in Figure 1.

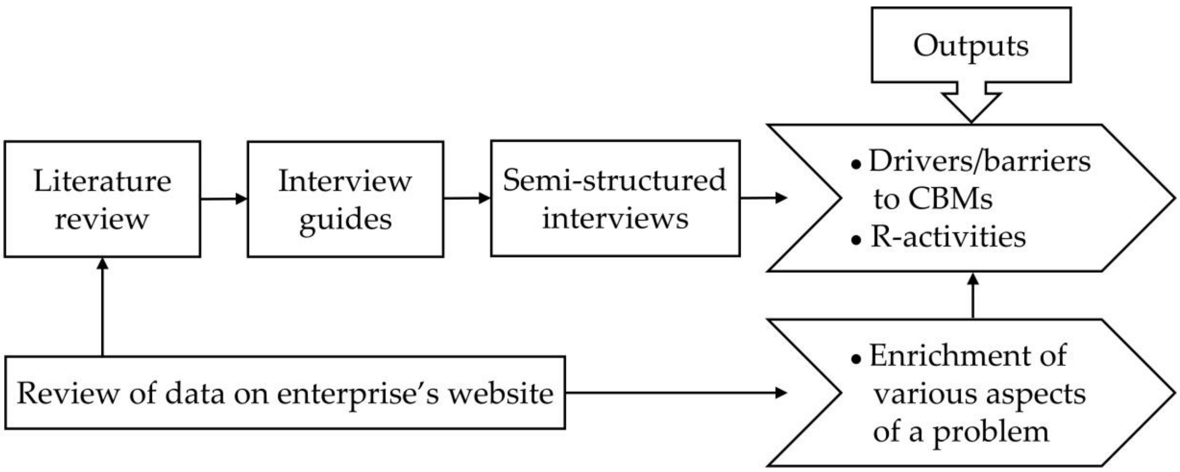


Figure 1. Research methodology review. Source: own elaboration.

3.2. Data Collection

Only one-to-one interviews were conducted [33]. In total, 7 semi-structured interviews were conducted with a business practitioner. The respondent was a manager employed in a position included in the highest management level (top management teams, TMT) in VIVE Textile Recycling.

Over the course of the interviews, open-ended questions were asked (see: Appendix A, Table A1), which allowed the respondent to explain complex issues. As a rule, the interviews were aimed at getting to know views on the factors inhibiting and enhancing changes in business models in the surveyed enterprise in which the respondent has been employed for several years. Basing on the interviewee's consent, the interviews were recorded and then all transcribed for further analysis. Data collection was taking place from November 2021 to June 2022. The data were then triangulated with publicly available information from the enterprise's website. In preparing for the interviews, information was gathered about the enterprise and its CBMs through a review of official documents, reports, interviews, press releases, and end-users' reviews. Making consultations with the respondent (VTR's internal stakeholder) was favouring the triangulation of the literature results and provided more details on the factors influencing changes in the business models already existing in VTR.

4. Results and Analysis

4.1. Drivers: External Environment

Changing business models is seen as the key to organisational success, especially in times of increased competition, advancing globalisation, and the advent of new technologies [50]. Following this trend, VTR is actively trying to redesign its business models.

The analysis of the content of the interviews allowed for identifying what and how drives the development of business models in an enterprise which has been successfully operating in the textile recycling sector for 30 years. The VTR's representative believes that there are three main factors driving VTR to change its business models towards higher levels of circularity: *"Here we have the three most important factors (. . .), but we are talking about the three main ones, absolutely the most important in my opinion"*.

From the perspective of the respondent's business practice, it follows that one of the most important driving forces behind the development of CBMs in an enterprise are the relevant regulations required at the international level: *"Very important factor is legislation at the European level, through which we move in the world of waste, which should be very precisely accounted for and landfilled. Legislation has a huge impact on this"*. As a result of changes in international regulations and policies, changes are made to national regulations specifying the conditions for running a business in the textile recycling sector, which may close the current directions of textile waste imports and open up new ones as well as (do not) support the transition to higher levels in the textile waste management hierarchy. External pressure (such as regulatory and policy pressures) means that through changes to regulations, governments and institutions may encourage or discourage businesses and consumers to or from adapting to CBMs. Therefore, it is important that the legislation on recycling and life-cycle extension issues should focus on both environmental performance and economic incentives.

At the same time, the respondent pointed out of regulatory tools is their change from time to time: *"Waste storage and processing issues. The legislator defines them very precisely and, what is more, wants to change them from time to time"*. For enterprises, this implies a change in the conditions of market competition, changes in customers' needs, and may reveal discrepancies between existing VTR's operating routines and competition requirements. This is because turbulent environment reduces the potential value of existing products due to changes in market needs, technologies and competing products. Therefore, adaptation to the new legal regulations is necessary for VTR to conduct this type of economic activity in accordance with the applicable regulations.

Gaps between the current configuration of operational routines in VTR and the requirements of the environment, if they have existed so far, they were only temporary (see further: lockdown in the event of the unprecedented COVID-19 pandemic, introduction of an ad hoc public holiday connected with National Independence Day in Poland on 12 November) [51] as VTR's capabilities were and are still adapted to the changing requirements of the environment. The achievements of this enterprise (e.g., [52]) show that it may use dynamic capabilities (e.g., [53]) to adapt to the type of changes in the environment in which it operates, knowing that a highly dynamic environment offers new opportunities which at the same time offer more options for improving existing operational routines.

In this interview, the respondent also highlighted the importance of the growing number of socially and environmentally conscious consumers looking for cleaner and more sustainable ways to express their attitudes through fashion. In the era of shifting away from the linear economy model and transition to the circular economy model, re-using and the best possible using of textile waste (i.e., second-hand clothes) become a necessity. Re-use is part of a circular economy which seeks for greater use of material goods. The main change noted only in this respect by VTR is the development of the market of *second-hand stores* (e.g., [54]). The respondent explained this in these words: *"Social awareness, which is key in this second-hand market, circular economy, CE. (. . .) Today is a complete shift in awareness. This is the glory of modern times. The whole peer 2 peer movement, reselling or donating clothes; second, third, fourth, fifth life. This is exactly the case with our stores as well. It is all the result* *of our social awareness which we create, but also which creates us. This social awareness is a huge factor of change. Because we have many such detailed factors, and I could list them for a long time"*.

Growing social and environmental awareness of the importance of re-using and recycling of old clothes drives the development of CBMs. Enterprises have already recognised the fact that consumers are increasingly seeing that their choices may have an impact on the environment. Therefore, enterprises begin to look at what customers buy, and VTR does the same or even more than other enterprises, thanks to a professional marketing team (e.g., [55,56]). Customers are aware that second-hand shops exist and have now overcome changes in the above-mentioned behaviour. Of course, second-hand clothing resale practices have always existed. People have long been selling second-hand clothes at flea markets or in second-hand stores. However, this "R-activity" offered by VTR is booming today. More and more buyers, as the awareness of the negative impact of disposable culture grows, begin to understand that fast fashion has little to do with sustainable development. They start to make choices guided not only by their own style, but also by environmental and social values. Therefore, slow fashion business models, such as a re-sale model (longer use of clothes) used by VTR, reflect a fundamental shift in customers' thinking and subsequent purchasing decisions. Consumers buying recycled clothes create a trend against fast fashion, which may limit the fast fashion industry, or at least its impact on the environment. Thus, social expectations are another factor driving the development of CBMs. However, according to Masi et al. [20] business practices related to green purchasing and customer cooperation are still not very widespread. Eco-design and in-house environmental management practices have a medium level of implementation.

4.2. Drivers: Organisational Environment

According to business arguments, apart from external pressure (legislative changes, customers' environmental and social awareness), changes in the internal environment of the enterprise, including those in the technological area, motivate VTR to re-design business models as well.

The respondent further argued that changes in VTR's business models are currently driven by the creation of modern business and technological solutions, which at the same time are an example of VTR's conscious operation taking corporate social responsibility and a circular economy into account: *"Technological changes related to digitisation, automation, but also other alternative methods of using waste, which directly translate into business models, because they create new business opportunities. This is a space for research and development, for new technologies. R&D is here"*. While discussing the future, the interviewee emphasises the role of new recycling technologies (e.g., [57]) along with sorting technologies (e.g., [53]) and the construction of installations for the pyrolysis of the discards from sorting processes, which are to respond to market challenges. Respondent explained this challenge: *"It takes energy to turn it [textile waste—authors' explanation] into a composite. In this approach, I will have my own power station in the form of pyrolysis. I will generate energy that will cover my composite needs. (...) But there are a lot of technical problems to be solved, but this is what we are here for to solve. (...) It is a project that is thoroughly researched. (...) This is the concept and it shows how it changes the structure of the enterprise. Well, circular economy generates R&D costs, it is absolutely a cost item"*. It is also worth mentioning that the technological transformation, which generates new business opportunities, is also emphasised by the European Commission in the study entitled "Circular Economy Perspectives in the EU Textile Sector" [58]. "R-activities" undertaken by VTR fit into this perspective.

In sum, the regulations at the European level and, by analogy, national regulations, social and environmental awareness of consumers towards sustainable development, "consumers' social and environmental awareness and attitudes towards sustainability", as well as product (i.e., innovative textile composites made of recycled textiles) and process (development and implementation of more sustainable methods of using textile waste) innovations based on, for example, digital technologies or materials engineering create a set of main drivers of circular practices in this enterprise, which push it to change its business models. Teece [59] also draws attention to the relationship between technological innovations and a business model, and stated that product or process innovation based on new technologies is often not effective without the appropriate adjustment of the business model. Therefore, VTR's activities in this area confirm the findings of Teece [59], because the implementation of new methods and technologies for the management of textile waste less harmful to the environment and most desirable by VTR is associated with the change of existing business models.

The respondent's above statements also reveal the very high cognitive ability of top managers, which contributes to understanding the value of the potential of new business models. This observation is very important. The mere fact that an enterprise has dynamic capabilities does not guarantee its success. The use of dynamic abilities is intentional, just like in the case of VTR. Although dynamic capabilities are embedded in VTR, the ability to assess and determine changes in resource configuration is already on the shoulders of top managers, including our interviewee. Dynamic capabilities are therefore a tool that top managers may use to manipulate the enterprise's existing resources and operational capabilities, and re-group them in order to create new configurations in response to the challenges of a changing market. As such, other very important enhancing factors for changes in circular models of second-hand clothing reuse and textile recycling are managerial capabilities.

4.3. Barriers: External Environment

This study also provides an overview of the factors which were preventing the top management from changing business models. The three most important of them have been described in detail. The first barrier mentioned by the respondent is the large scale of business which in crisis situations requires top management to solve many times more and more complex decision-making problems in various dimensions, such as suppliers, customers, employees, revenues and costs, than required by a small scale of business. One of the crisis situations took place in Poland on 13 March 2020 when, by means of the Regulation of the Minister of Health, an epidemic threat had been introduced in the territory of the Republic of Poland, covering the period from 14 March 2020 until the state was recalled [60], which caused serious disruptions in the activities of the surveyed enterprise. The scale of the VTR's business, previously well-established in terms of infrastructure, people and processes, required at that time a thorough and at the same time quick analysis of its various aspects, and the creation of an action plan aimed at making the enterprise's operation more flexible in the conditions of turbulent changes in the environment. Of course, the introduced changes are covered not only by VTR, but also by the ecosystem in which VTR is embedded. The respondent expressed it in these words: *"The first factor is the scale of an enterprise. (...) When we run over 40 stores directly across Poland, medium-sized and large-area stores, it is not simple anymore [managing such a business—author's explanations]. For example, such a problem as changing the size of store is of great importance (...) At over 40—it is* [i.e., changing the size of stores, termination of contracts, changes in the work schedule—author's explanations] *"n" times more difficult. It is not 10 times more difficult, but many times more difficult, that is the scale of the enterprise is a limiting factor. Just like in every area of activity"*. According to the respondent, a serious obstacle to changes towards more circular activities is the complexity of the chain of cooperating business partners in connection with the large scale of business.

Problems in managing a large retail chain appeared in a crisis situation, because the introduced business bans in connection with the SARS-CoV-2 coronavirus pandemic also affected the VIVE Profit chain of stores. They lost their capacity to function from day to day. In the short term, this was associated with a huge drop in their revenues and thus difficulties in meeting their liabilities (e.g., [61]). As the epidemic progressed, the number of bans and restrictions on their activities grew (i.e., limited number of customers served in a store) (see: [60]). The introduced restrictions caused by the COVID-19 pandemic situation also delayed the implementation of planned projects to change the business models of the VIVE Profit chain of stores throughout Poland. The respondent explained this situation in these words: *"The events were crazy. After total closure, the shipment was suddenly unblocked and left overnight. Stores could trade and then suddenly could not trade. The first lockdowns completely ploughed Poland (. . .). And all this resulted in: stores opening, stores closing, limiting the number of people in the store, then closing stores again, opening stores again. All this had a significant impact on the current work, but also on the operating costs. This also destroyed the stability, and thus threatened the implementation of the change projects being under implementation, because then all the efforts and resources went to support the enterprise and make it more flexible in this respect, which nobody planned to make more flexible"*. As may be seen, unprecedented events influenced the need to re-think the enterprise's supply chain in terms of resistance to various types of variability, not only those in the past, but also these which would be in the future. Therefore, the supply chain would be created with flexibility in mind, as emphasised by the respondent, so that it may guide VTR through the following bigger/smaller disruptions in the supply chain. This would be in line with the suggestion Sarkis [62] that a crisis is a difficult and at the same time inspiring challenge for managers, because there are opportunities to improve the enterprise, for which there would be no will of stakeholders under normal conditions, including sufficient mobilisation of managers' attention for such changes.

During the COVID-19 pandemic, the enterprise was also unable to continue production activities in the short term. The production lines were closed until 10 April 2020. Workers' health and safety were a major concern. When VTR was able to continue its activity, limiting the possible transmission of coronavirus among workers in the workplace became a key challenge. VTR has implemented safety measures to protect its employees from infections or to prevent the spread of coronavirus by limiting physical interactions during work and introducing enhanced sanitation measures, among others.

As mentioned above, the disruptions caused by the COVID-19 pandemic had negative effects in the area of manufacturing activities, such as that when the enterprise was suffering from severe obstacles to its operations, including supply chain disruptions caused by problems with smooth border crossing (see: Appendix A, Table A2, ID.1).

It may be said that during the unprecedented COVID-19 pandemic, the conditions of the market game changed significantly and abruptly. As a result, the main source of costs in the enterprise, in accordance with the above findings, was the maintenance of downtime in production. Maintaining a reserve of resources (personnel, machinery, equipment, buildings) related to adapting to changes in the environment caused by the introduction of the above-mentioned sanitary cordons at the border generated costs for the recipient, i.e., VTR in this case.

These recent developments have shown that management may begin to consider over-reliance on Just-in-Time (JIT). The weaknesses of the JIT supply chain model which even led to a global logistics bottleneck were revealed: *"The pandemic has also made our logistics systems very difficult for us (. . .). Shipments and cost of shipment, that is unintentional situations, but such on a macro scale. This pandemic really hit us, but not only us . . . "* As may be seen, the COVID-19 pandemic has changed the business world in an unprecedented way. Enterprises applying Just-in-Time strategies, just like VTR, were drastically affected by forces beyond their control. These enterprises had an increased susceptibility to external disruptions. For this reason, management had to develop strategies to deal with these short-term discontinuities and considerable uncertainty in order to survive.

Although the effects of the global COVID-19 pandemic are fully noticeable in the minds of the top management team, this is not the first major event to cause significant disruptions to the VTR's supply chain. A public holiday on the occasion of the 100th anniversary of regaining independence by the Republic of Poland on 12 November 2018 [51] was another event that also posed a logistical challenge (see: Appendix A, Table A2, ID.2).

This shows that disruptions have always (i.e., before, during the pandemic and thereafter) been part of supply chain management. However, the last crisis situation was even more unpredictable than the previous ones. As a result, the Just-in-Time supply chain models became a burden, not only for VTR, as the effects crossed the organisational boundaries of VTR and affected other stakeholders (i.e., suppliers, customers) of the circular ecosystem [5]. Thus, the dynamic and unpredictable business environment and global exposure of VTR show that there is an urgent need to re-think supply chain models to better reflect today's realities.

4.4. Barriers: Organisational Environment

What is more, the respondent indicated that another factor which slows down changes in business models is significant geographic diversification of sales markets: *"A very large variety of markets we work with. If my target market is one market and I know it perfectly well, then I adapt to it, predict it, react to it. And if my target markets are many different markets such as the Western Europe, Poland as well as Russia, Kazakhstan, or even further markets such as Pakistan, South America, Africa, then we come to a situation in which I have many markets and there is no economic justification for knowing them so deeply* [markets—authors' explanation]. *I am not able to know all of these markets so thoroughly and simultaneously. It is very hard to have several irons in the fire, that is, to have one level of quality for Western markets, because there is higher quality required, another level of quality for Polish stores and another level of quality for Kazakhstan, and yet another level of quality for export to India. It is simply so difficult. Although having the knowledge of this weakness and despite this awareness, it is difficult to find a solution to this problem, so that it would be obviously economical and would also involve access to such staff that would be able to crack it on. Theoretically, it is all possible to be cracked on, but it is not simple"*. The respondent's statement indicates that export is the form of foreign expansion which allows VTR to use the potential of foreign markets. However, these markets are very different from each other (e.g., [32]). Sale of products for the above-mentioned geographically distant markets causes VTR to experience problems due to uncertainty, which in this case is equated with an information gap resulting from, among other things, large geographical distance between contractors, fluctuations in the economic situation, different needs of customers. Therefore, a big challenge for an enterprise which offers products practically all over the world is to match the offer to local needs.

The third important inhibiting factor of change in BMs in an enterprise which constantly improves its product offer and discovers completely new paths of business development (VTR often operates outside the beaten path and behavioural patterns) is the readiness to take the so-called "being the first on the market" risk. In the case of such innovative products as textile composites (e.g., [63,64]), new recycling technologies along with sorting technologies i.e., [65], or the construction of a textile waste pyrolysis installation (a case of large-scale production volume in the textile recycling sector), there are no well-trodden paths for the enterprise's development. VTR has to work out all this from scratch and each investment involves some risks. They are examples of courage in action which allow for undertaking and consistent implementation of entrepreneurial ventures despite the natural risk in such situations.

This study documents that risk is always present in business and includes both negative and positive effects of events. For example, "being the first on the market" gives the chance to reach for the "Schumpeter's pension", i.e., the "priority rent in the market", the "candy" as called by the respondent. However, it is burdened at the same time with "entry costs" (i.e., technology and R&D expenditures) which do not have to be borne by subsequent players entering the market. As a consequence, it may mean that the competitor's product or technology would be much cheaper. Because the competitor, by analysing an already functioning market, is able to better develop a product or technology. The respondent told about it in these words: *"Well, that is the problem, but we also think it has some advantages. So, we are looking at the market where we are the pioneer in most cases. Especially in Poland. And generally, in this part of Europe. And this is, on the one hand, the <<first advantage>>, and it is OK, but on the other hand, we are the <<first in costs>>". Well, the enterprise which is the first, then it goes through this minefield; when it crosses this minefield, it is the first for the <<candy>> which is there. (...) but it also bears all these risks and costs. And it is* *not just about the risks associated with a sudden entry with a new technology or a new model. It is not just that this particular process or technology will not work. In developing new activities, the path towards them itself is equally important. And being the first, I risk that this path will also fail, apart from the technology itself"*.

These studies and the existing literature [27,37,44,66] clearly show that innovations may be commercialised in different ways, which means that an identical innovation commercialised in different ways is likely to bring two different results. The commercialisation of technology includes not only the physical implementation of technological changes, changes in hardware resources, and finally changes in production processes. It also includes a number of additional factors—sometimes equally costly—related to communication with the market, marketing message, or even educating the market itself. A number of commercialisations do not bring the intended business results, not because they did not have the potential, but they were burdened with enormous costs of education, transforming the target market, etc. Costs that imitators bear only a fraction of the original outlay. The commercialisation paths chosen by enterprises may be highly diversified, despite the fact that they are based on a similar technological potential or a similar optimisation of processes. The absorbed financial resources may or may not be returned. It means that the BMs do not represent a single objective value. Innovative BMs rather develop from commercialisation possibilities which are realised by a unique setup [67]. Our findings confirm the views of Chesbrough [37] and Breier et al. [44] who claim that BMs are necessary for enterprises and require constant improvements and adjustments. Therefore, it would be desirable for top managers to see the potential for improvements and adjustments [66,68].

Based on the results of this study, it may be concluded that experimenting and trying out different ways of implementing BMs to achieve enterprise's goals requires the effort and attention of different members of this organisation [66], including additional interaction and collaboration between managers and individuals at different levels and from different units in the enterprise [22,45], who may distract managers from matters important to the enterprise. Because some issues, tasks or domains (creating value or delivering value or capturing value) attract more attention or priority than others [66,69,70]. The respondent highlighted these issues as follows: *"And if I am doing this, that is implementing an innovation, as the first one on the market, I have a lot of additional communication with the staff and people. Lots of extra thinking, many such side roads where you can go astray and they can turn out to be dead ends. A lot of the enterprise's energy can be absorbed in this way, which means that the focus of the enterprise starts to fade a little. (. . .) When, just like in our case, we are the first. Everybody says that being the first is so great but forgets about the high costs of not only the potential risk, but also organisational distraction carried by "being the first". How easy it is to get lost, how easy it is to confuse goals. And to get bogged down in some minor topics"* (see more: Appendix A, Table A2, ID.3).

The study also found that "being the first" involves making improvements to an enterprise, which may reduce its operational efficiency before improving it in the initial period. As Obłój [71] (pp. 103–104) claims, there is no simple solution to this problem, which often appears in management practice as an "either-or" dilemma, while it must be perceived as an "and-and" necessity. The enterprise's successes cannot be postponed until an undefined future. The enterprise must be successful both now and in the future. Therefore, one of the key issues is the dilemma of how to build the enterprise's future without sacrificing the enterprise' current performance.

In sum, large-scale business in crisis situations, a large scope and range of geographic diversification of outlets in the perspective of the consequences of the information gap, and the readiness to take the "being the first in the market" risk (lower level of this readiness in relation to that required by a given situation) may be those factors which inhibit the enterprise from implementing changes in business models.

5. Discussion

5.1. Drivers to CBMs

This study is part of the ongoing broad discussion on the antecedents of business models by highlighting enhancing and inhibiting factors. Business models are not static; they are dynamic [66,72] and their role is strategically important [44]. The literature studies indicate that the business model takes shape through experimentation, which may vary depending on organisations and competitive environments [68,73]. Therefore, the development of a business model requires constant changes, adaptation, experimentation, and thus the constant attention of managers [74]. In this context, the enhancing factors create the need to change and further support the development of BMs, which may result in new prospects and profit potential for enterprises which seize the opportunity for change.

However, it should be borne in mind that changing existing business models may put the enterprise's actual business model at risk, and enterprises may hesitate to change and thus leave too many activities unchanged. Changing value creation, value proposition and value capture may not be radical enough. As a consequence, future development and changes to the business model may be too limited [66]. In order to increase the chances of success of the new, alternative business model, it should be adequately supported by managers [68,75] who saw the potential for improvement.

The main factors enhancing and inhibiting changes in the existing CBMs in VTR were identified through interviews. The set of main driving factors for the development of CBMs in VTR includes relevant regulations at the European level, appropriate technologies and digitisation, and increasing social and environmental awareness of consumers and managerial capabilities. Table 1 shows the categories of drivers explored in this study.

Table 1. Drivers and barriers to CBMs.

Driver Category	Description
Organizational environment	• Managerial capabilities • Appropriate technologies and digitisation (an enterprise itself creates and implements new, more ecological and efficient technological solutions in the field of reuse and recycling as well as related to the enterprise's digitisation)
External environment	• Relevant regulations at the European level • Increasing social and environmental awareness of consumers
Barrier category	**Description**
Organizational environment	• Readiness to take the "being the first in the market" risk • A large scope and range of geographic diversification of outlets in the perspective of the consequences of the information gap
External environment	• Supply chain complexity and supply chain collaboration in connection with a large scale of business in crisis situations

Source: own study.

These factors may inspire or underpin new and developed business models in enterprises in the textile recycling sector. They may influence enterprise's decisions, among other things, to move up the tiers of the "textile waste management hierarchy" [76], which have long-term implications and require changes to existing business models. For example, changes made to whether the alternative fuel is a fully functional product or a waste see: [34,76]. In this context, the dynamically changing societal temporal construction of the concept of "waste" will strongly influence the perception and management of material resources in the design of CBMs [25].

Lewandowski [77] in his research argues that implementing the principles of circular economy often requires new visions and strategies as well as a fundamental redesign of product concepts, service offers and channels towards long-life solutions. It is worth emphasising that technological and business ideas have economic value only when they are commercialised through the enterprise's business model. In this respect, technology and innovation alone have no measurable economic value [75]. Chesbrough [78] even claims that "a better BM often will beat a better idea or technology" [75].

Thus, the ways in which enterprises successfully implement new technologies or other innovations are largely related to its CBMs.

In addition, it should be added that enterprises should pay great attention to digitisation, taking advantage of opportunities in technology, processes and markets. Digital technologies may currently take various forms, including e-platforms (i.e., B2B online store, B2B wholesale platform) see more: [50], or the development of systems automating processes based on the so-called artificial intelligence and deep machine learning algorithms. It was indicated that digital technologies are the basis of digitisation in an enterprise. Based on the suggestions by Bouncken et al. [66], the advances in digital technology would require enterprises to develop and implement a wide range of digital activities (i.e., improved or new internal processes and within their supply chains and environment) in business models. Enteprises should therefore consider appropriate and perhaps develop new business models in digitisation. However, as suggested by Reim et al. [79] it is important not to choose an overly ambitious business model where the risk of failure is high. Rather, the enterprise should strive for the gradual development of a given business model.

Further research provides evidence that the growing segment of ecologically and socially minded individual and institutional customers in recent years is also putting pressure on the introduction of business models to support them. For this reason, enterprises verify their business models from time to time. The example of the VIVE Profit retail chain shows that after the COVID-19 pandemic, the second-hand market is undergoing a revolution. Small and local second-hand shops are disappearing, and large-scale networks and e-sales platforms with second-hand clothes are growing.

These research findings are in line with recent evidence provided by Mostaghela and Chirumallab [5] who claim that the retail sector is evolving not only as a result of technological advances, but also due to crisis situations as well as governments and customers' new requirements for ethical and sustainable products.

Currently, without focusing on an organisation's customers, any strategy will eventually fail in a competitive environment [80]. According to Jansson et al. [80], customer focus is the degree to which an organisation views its purpose as creating satisfied customers and the extent to which the organisation puts a customer first. Thus, the enterprise's main goal must be the satisfaction of its current and future customers. In this case, the enterprise guided by social responsibility strives to achieve environmental and social goals which go beyond the legal requirements, and thus commits itself to achieving better environmental performance. Environmental impacts need to be integrated into the global process of enhancing productivity and competitiveness [81].

5.2. Barriers to CBMs

Our research also broadens the existing knowledge about the factors inhibiting enterprises from introducing changes in business models. These factors include: supply chain complexity and supply chain collaboration in connection with a large scale of business in crisis situations, a large scope and range of geographic diversification of outlets in the perspective of the consequences of the information gap, and the readiness to take the "being the first in the market" risk. Table 1 shows the categories of barriers explored in this study.

This study revealed that the enterprise has faced, for the first time since its thirty-year international operation, a serious threat to its supply, failure to meet its delivery times and operational efficiency in an uncertain environment. Recent disruptions have demonstrated the dangers of the supply chain built around JIT strategies, which have become serious problems, not only from an organisational, but also inter-organisational points of view. VTR and other enterprises from this sector suddenly needed appropriate mechanisms to fix themselves, i.e., ones which would correspond to the challenges of the modern world. This would be in line with the findings by Ritter and Pedersen [82] who emphasise that the COVID-19 crisis is going to affect established business models (BMs). These insights therefore contribute to the debate on the pros and cons of highly coordinated global manufacturing supply chains.

During this serious crisis, other important weaknesses in the enterprise's operations were also revealed, such as preparation for disasters, or the organisation and conditions of working in executive positions, taking the new ad hoc rules and regulations on hygiene as well as social distancing into account. This required the implementation of new ways of arranging the enterprise's operations.

Building on the results of this study, lockdown has contributed to changing the way business in the textile recycling sector may be conducted in the future. Crises have one important feature, namely, they provide an excellent "cover-up" and are an excellent motivating factor, an ideal element of permission for change. If there were no crises, organisations would be less active. Crises serve to renew organisations and accelerate changes. This is perfectly illustrated by the metaphor—*"Sequoias like fires because then their bark bursts and they can grow larger"* [83] (p. 190).

Moreover, Meyer et al. [84,85] (p. 93) described the pandemic environment in which the VTR was operating: *"From time to time, organizational environments undergo cataclysmic upheavals—changes so sudden and extensive that they alter the trajectories of entire industries, overwhelm the adaptive capacities of resilient organizations, and surpass the comprehension of seasoned managers"*.

However, according to Obłój [71] (p. 93), managers consistently make mistakes and may do so. Therefore, it is obvious that organisations would fall into periodic crises because they are too complex systems to be fully steered and controlled, no matter what illusion of control supervisory boards and managers want to maintain [71]. At the same time, the way in which leaders intend to balance solutions for creativity and product innovation with administrative solutions, such as risk management and management control, is important [86].

The respondent expressed a similar opinion in the above quotations, pointing not only to the very issues of the risk of these mistakes and difficulties in management, but also to the risk of losing the enterprise's focus on achieving goals and paying too much attention to solve smaller problems.

Koźmiński [83] (pp. 197–198), in turn, argues that cognitive limitations concern the recognition of operating conditions by managers and are obviously related to a lack of competences. He emphasises that it is a sin not to recognise crisis symptoms, conflicts and an excess of polemics and debates. Moreover, he claims that they should give top management food for thought, and are often ignored or misinterpreted, too hastily and superficially interpreted. In his opinion: *"(. . .) it is a mistake to try to implement difficult, ambitious plans too early or too late, in unfavourable conditions"*.

Concluding that the ability to properly read and understand the situation of an organisation is extremely important. Thus, this managerial skill is very important in making decisions. At the same time, according to Obłój [71] (pp. 96–97), every more important decision is made in the conditions of incomplete information; otherwise, there is no problem of choice and decision at all. In his opinion, the key mental problem of managers is the acceptance of uncertainty.

This quantum discontinuous change described by Meyer et al. [84], now caused by the unprecedented COVID-19 pandemic, also required a response from VTR. Top management at VTR has developed strategies to deal with short-term discontinuities and significant uncertainty by making significant changes to components and/or their configurations in the existing CBMs. These solutions enabled the enterprise to overcome the crisis.

However, bearing in mind the earlier suggestions of North [87] concerning a new equilibrium, it continues to change after such a serious disturbance. If so, according to Hitt et al. [85], even after the COVID-19 pandemic, long-term strategic changes may be needed to ensure that enterprises in many industrial activities, and VTR is among them, may operate in the newly created competitive environment resulting from technological, social, political, and institutional changes [88] which resemble the causes of environmental shocks explained by Meyer et al. [84].

These factors influence an enterprise's decisions when it comes to creating new ideas [27]. It has been emphasised in the management literature that enterprises need to identify or get ideas for new BMs even outside their boundaries (e.g., [44,89,90]), which are burdened with a high degree of risk [27]. Simply, enterprises have to take risks to increase the likelihood not so much of survival as of growth and success [71]. However, this risk must be handled by the enterprise's ability to take it.

In sum, VTR's product life extension and recycling models faced supply chain and market challenges. The findings of Wrålsen et al. [13] are identical as he argued that circular supply business models are mainly threatened by the supply chain and market barriers. Identification of these challenges is an indication for decision-makers and politicians in the search for solutions in the area of regulation and appropriate support for entrepreneurs in the face of crisis situations or the requirement of effectiveness of a specific "R-activity".

The above considerations are summarised in Table 1. Enhancing and inhibiting factors for the development of circular models of second-hand clothing reuse and textile recycling in VTR are grouped according to two categories as to their origins: internal and external to an organisation. Previously, similar categories were proposed by Galvão et al. [10] for the grouping barriers to CMBs. This division was also used for drivers to CBMs.

Our research findings indicate that implementing of circular actions in an organisation is largely dependent on regulations, especially at the European level, and increasing social and environmental awareness of consumers, i.e., on factors included in the external environment in which the enterprise operates. This suggests that the previously described wholesale and retail of second-hand clothing is evolving not only as a result of the digitisation of commerce (i.e., e-platforms: B2B online store, B2B wholesale platform) (see more: [50]), but also due to new government and customers' requirements for ethical and sustainable products. Social and environmental awareness of consumers and proper legal regulations are crucial for the successful implementation of circular business models. However, few studies focus on the role of customers in enabling circular business models [5].

Organisational factors such as the capabilities of the management team responsible for developing and implementing CBMs are also of great importance. It is believed that these capabilities help VTR to overcome obstacles on its way to change. In addition, the developed and used technologies for recycling textile waste, better in terms of the environment, which allow to obtain textile composites (i.e., composite board) with better properties and their recycling uses less and less energy, and in the near future the discards from sorting textile waste processes (the so-called waste which does not meet the prescribed recycling requirements) are an equally important factor facilitating the sustainable development of CBMs. Other recent studies have also recognised the role of technology in business models based on the reuse and recycling of waste materials [91]. This indicates that enhancing factors create a need to change and further support a CBMs (Figure 2).

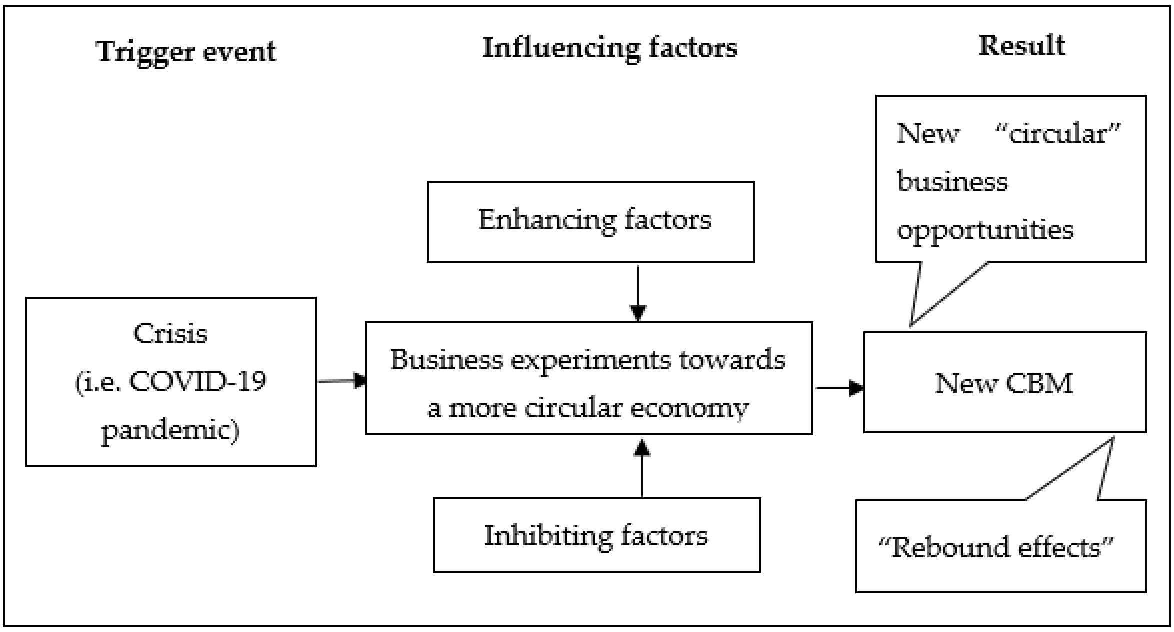


Figure 2. Crisis—New CBM relationship model in the context of influencing factors. Source: own elaboration.

On the other hand, the reported barriers seem to originate from the internal limitations experienced by an organisation, such as the readiness to take the "being the first in the market" risk, a large scope and range of geographic diversification of outlets in the perspective of the consequences of the information gap; on issues external to organization, such as supply chain complexity and supply chain collaboration in connection with a large scale of business in crisis situations. According to the respondent's statements, VTR faces these challenges as temporary problems to be overcome. Nevertheless, these barriers may delay the achievement of higher levels circularity (Figure 2).

The so-called drivers and barriers to CBMs discovered by us will complement or exemplify those previously identified by other researchers (e.g., [5,9,10,43,91]). Therefore, our findings contribute to the ongoing discussion on circular business models by expanding the existing knowledge base in this field. Our theoretical research contribution is to deepen our understanding of drivers and barriers and their links to the development of CBMs.

However, it is worth emphasizing that CBMs might not be more environmentally sustainable. Perceived savings from circularity can sometimes lead to rebound effects by increasing consumption of other resources. Business experiments conducted by companies that may have started out as "circular" or sustainable, could either create new "circular" business opportunities, or move them towards linearity through unintended "rebound effects" [12]. The above discussion is summarised by the conceptual model presented in Figure 1.

On the basis of presented findings, the crisis—New CBM relationship model for the textile recycling sector, is proposed (Figure 2). The model comprises the results and shows that a crisis can be a trigger event [44,82,83] to start changes in established circular models of second-hand clothing reuse and textile recycling, through business experiments towards a more circular economy, which can help firms that are shut down to create new CBMs and open up again. This overall finding is consistent with recent evidence provided by Kraus et al. [27] in a cross-industry context from various European countries, that the role of new BMs may be even more strategically important in the context of the crisis. While individual enterprises adjust BMs only temporarily to maintain liquidity, it turns out that a new business model innovation (BMI)—initiated in response to the crisis—may also have long-term consequences. In other words, the crisis may result in new prospects and profit potential for enterprises which seize the opportunity for change.

6. Conclusions and Practical Implications

The textile recycling industry is one of those industries which may benefit economically from efforts for CE, that is they aim to address the challenges not only of resource scarcity but also of waste disposal in a win–win approach with an economic and value-added perspective. This means that enterprises in this sector, by thinking more specifically about promoting sustainable development, may want to engage in CBMs.

The carried out analysis of data collected directly from the top manager during interviews in conjunction with secondary data provides a unique, credible and valuable justification for the formulated practical implications, which may be of a great interest to a broad interdisciplinary audience. Therefore, major factors discovered which enhance and inhibit the development of circular models of second-hand clothing reuse and textile recycling may be the subject of intervention or support of business managers, practitioners, consultants and policy makers, as well as academics by minimising the negative impact of post-consumer textile waste on the environment.

For instance, top management of enterprises with Just-in-Time (JIT) supply chain models should be aware of the potential long-term implications for supply chains in the post-COVID-19 world. Given the uncertainty surrounding the consequences of the SARS-CoV-2 coronavirus, it is theorised that it is worth re-thinking supply chains for resilience to various types of variability in the competitive landscape. To the best of our knowledge, this would build greater long-term resilience of enterprises to the crisis and increase the chances of success. If top management develops a new standard, it should be associated with a better understanding of risk so that risk management stops the destruction of supply chains caused by crisis situations. Thus, insisting on JIT supply chain models may not be the best way to go. It is worth considering that several stakeholders need to work together to strengthen drivers and overcome barriers to retrieve values from used clothing.

In addition, thinking about the circular business model is ecosystem-oriented, not a central enterprise, should be taken into account. CBM in fact functions at the level of other ecosystem participants, which can be both B2B enterprises (i.e., suppliers, wholesalers, retailers) and private individuals who are end users in the B2C market. This means that changes in the circular business model may require changes at the system level, i.e., they should take cooperation with external partners into account. After all, a business organisation is part of a larger ecosystem. Therefore, the above suggestions for solutions to the problems of strategic cooperation with partners in the supply chain built around JITs in crisis situations provide, at the same time, new information to the literature.

Moreover, the closure of VIVE Profit physical stores proved that running an on-line business has become not only a good practice, but a necessity to maintain operational efficiency. Thanks to increasing numbers of buyers in the on-line space, these stores may be better at reaching their target groups, and thus the risk of failure would be relatively lower in the event of a pandemic that may be still observed. Therefore, today's best practice in the trading industry is the e-commerce model, or hybrid business models.

Based on the respondent's statements, the view that new technologies open the door to many business models used in the recycling industry is highlighted. Osterwalder et al. [92] also state in their study that managers analyse the adequacy of the current business model to environmental pressures and design a new business model.

Due to the emergence of these new technologies and the invention of new products (i.e., textile composites), BMs in enterprises in the textile recycling sector may have to be improved or changed to new ones. According to Osterwalder et al. [92], new business models may become the goal to be achieved and may guide planning, change, and reaction. In this context, understanding the enterprise's business model may facilitate and rationalise the choice of infrastructure. This suggestion also applies to the integration of digital technologies and their use in new business models. This may require managers to engage in digital transformation and the digitisation of business models. Bouncken et al. [66] have recently found that enterprises may already apply digital technologies to improved or innovative internal and external processes and integrate them into new business models.

At the same time, it is important to foresee the potential environmental impact of new business models at an early stage in order to maximise their impact reduction potential. To do this, the organization must give a senior manager the resources and authority to define and launch business-model experiments [78].

From a practical point of view, this article also aims to deepen understanding of how policy makers can facilitate the development of CBMs in the textile recycling sector. Our findings are consistent with the evidence of Evans et al. [45], Ranta et al. [38] and Galvão et al. [10] who recognise that policy may have an impact at the individual enterprise level as well as at the broader level of the industrial system by appropriately modifying stakeholder's behaviour through appropriate policy interventions such as: regulation, legislation, taxation, education, and incentives. For instance, Galvão et al. [10] suggest that tax incentives are needed to help enterprises to invest more in circularity.

Thus, the contribution of this study to the theory of crisis management, supply chain management, to the emerging CBM literature as well as the implications for practice indicate that the studies on the development of CBMs in the textile recycling industry are empirically important in this industry.

7. Limitations and Future Studies

This study has some limitations that should be taken into account when interpreting its results. Firstly, a case where the enterprise is actively working on the development of its CBMs offer was chosen, and insights from its 30 years of experience were obtained. These observations, however, are limited to a large Polish enterprise dealing in second-hand clothing reuse and textile recycling into innovative textile composites used in industry (i.e., construction industry) on a global scale. Thus, adopting a broader case selection would provide scope for better cross-case analysis.

Secondly, research results based on the subjective assessment of the respondent should be treated with caution. Case study does not allow for an empirical generalisation in probabilistic or deterministic terms [44]. Therefore, presented results should be treated as ideas that provide reasonable expectations for similar results in other cases of enterprises dealing with reusing and/or textile recycling and which may be confirmed or falsified by future quantitative research.

Therefore, future research could conduct further empirical studies to validate or extend the present study findings through quantitative analysis. Thus, this article may be seen as the basis for further research.

Author Contributions: Conceptualization, A.W.-K., J.K., B.Z., P.B. and A.P.-O.; methodology, A.W.-K., J.K., B.Z. and A.P.-O.; investigation, A.W.-K., J.K., B.Z. and A.P.-O.; writing—original draft, A.W.-K.; formal analysis, A.W.-K., J.K., P.B., B.Z. and A.P.-O.; writing—review and editing, A.W.-K., J.K., P.B., B.Z. and A.P.-O.; resources, A.W.-K., B.Z. and A.P.-O.; supervision, A.W.-K.; final editing and revision, A.W.-K. and A.P.-O. All authors have read and agreed to the published version of the manuscript.

Funding: The publication was co-financed under the subsidy granted to the Jan Kochanowski University of Kielce (Project no. SUPS.RN.22.009) and the subsidy granted to the Cracow University of Economics (Project no. 014/ZZO/2022/DOS).

Data Availability Statement: The other data are not publicly available due to their containing information that could compromise the privacy of research participants.

Acknowledgments: The authors would like to thank the anonymous peer reviewers.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Interview guides.

Context	Interview Question
Introduction question	How long have you been working for company X and what is your current position?
	How do you understand the concept of circular economy /sustainable development?
	Has your enterprise take any actions which are aligned with circular economy/sustainability development? What are these activities?
	What business model does your enterprise use?
	How does your enterprise confront the business model with reality and verify the assumptions on which it is based?
	What are your enterprise's plans to continue investing in circular economy/ sustainable development?
Context for RQ1	What, in your opinion, mainly enhances your enterprise to implement new circular processes and products? Could you explain it?
	What do you think will be the future opportunities for your enterprise?
	What, in your opinion, determines the success in implementing new circular processes and products? Could you explain it?
Context for RQ2	What, in your opinion, mainly inhibits your enterprise from implementing new circular processes and products? Could you explain it?
	What do you think will be the future threats for your enterprise and the consequences of them?

Table A2. List of selected full responses of the Respondent.

Respondent's Response ID	Respondent's Full Response
1	"Those events were a limiting factor. Actually, we are still being affected by their consequences. Our raw material shipments suddenly got stuck at the borders. We were totally swept off by the pandemic. All our development plans were put into question. The pandemic caused a huge scale of damage to us. That is, not the pandemic as such, but an uncoordinated government response to it. The biggest problems were lockdowns being introduced practically overnight, minute by minute, in a way which had been impossible to predict before. Basically, it was done without any communication with the market. For example, in the initial period, there was no formal lockdown in Poland, but the introduction of the so-called sanitary cordons at the border made our lorries, that is our suppliers got stuck for 4–5 days. We have a plant which has to receive 40 lorries every day. Every day. And it cannot receive more than 40 lorries. Because if we received 100 lorries, extra 60 lorries would block Kielce [Kielce—a Polish city in the central part of the country, where the VTR's manufacturing plant is located—authors' explanation], because they would block all those streets around. Am I right? In our plant, one lorry arrives and another one leaves. All the time. Collection and shipping all the time. And then suddenly all such shipment got stuck at the border. This means that two thousand people did not get raw material to work and no one planned it. Not to mentions the costs."

Table A2. *Cont.*

Respondent's Response ID	Respondent's Full Response
2	"Such an example, introducing 12 November as a day off from work cost us 25 times more than a standard Sunday costs us. It is also a day off, that is a standard holiday, a standard day off. Why? Because this 12 November was introduced by law at the last minute just before 12 November. [It is about an additional day off related to 11 November, i.e., the Polish National Independence Day. It was on 12 November, based on the Polish Parliament's act in connection with the 100th anniversary of regaining independence by the Republic of Poland in 2018.—authors' explanation] While our foreign partners had already sent us shipments and expected those shipments from us under the concluded contracts. And suddenly we said that we would not receive the shipment, because we were not allowed to do that and we could not send an employee on a non-working day as overtime to receive that shipment, because it was a holiday. We had to explain them that they could not drive lorries around Poland on holidays (. . .). A day off from work bears all these consequences. Our partners did not understand why this was happening. How was it possible that suddenly there was a holiday which had not been included in the production plans? It should be understood that these costs are completely different than when we know that there is a day off. When getting to know of it in advance, such a day is simply taken out of the production schedule. In the production schedule, which we close in January, we inform our contractors about the production plan up to December. Everybody knows when there is a working day and when not, when we work our free days off, but it does not concern only us, everyone does it. In our scale, 40 arriving-leaving lorries each day are booked, contracted, etc."
3	A good example is the franchise business model. I go to the nearest Żabka store [Żabka is a chain of convenience stores in Poland based on the franchise business model.—authors' explanation] and see that such chains as Żabka are successful and replace some local shops. Why? Well, because I can see the way the store is organised, delivery rules, network contracts, etc. I can see that it works. So, I can copy this model, right? Moreover, I can even improve it. But, if I were the first such chain as Żabka in Europe or even in Poland. So, let us assume that we go back in time and there are no such franchises, then please see how many enterprises had tried it and how difficult the issue was. Please see how many of them failed. Developing your own franchise is not as easy as it seems and as many entities thought, even though it seems that the very essence of the franchise is not very innovative. Franchise business models are known to us. I do not know, but they have been on the market for 70 years, at least the mass ones. It seemed that McDonald's has exploited them to the limit. Since McDonald's, one could speak of an actual franchise factory. These franchisees manuals are perfected there. And this does not change the fact that if someone has to develop a new franchise, it turns out to be not as simple as it might be, although having all these manuals and all this great knowledge. So let us turn this example into the implementation of a completely new technology, new business models.

Source: own elaboration.

References

1. Akter, M.M.K.; Haq, U.N.; Islam, M.M.; Uddin, M.A. Textile-apparel manufacturing and material waste management in the circular economy: A conceptual model to achieve sustainable development goal (SDG) 12 for Bangladesh. *Clean. Environ. Syst.* **2022**, *4*, 100070. [CrossRef]
2. Rahman, S.S.; Siddiqua, S.; Cherian, C. Sustainable applications of textile waste fiber in the construction and geotechnical industries: A retrospect. *Clean. Eng. Technol.* **2022**, *6*, 100420. [CrossRef]
3. Briga-Sá, A.; Gaibor, N.; Magalhães, L.; Pinto, T.; Leitão, D. Thermal performance characterization of cement-based lightweight blocks incorporating textile waste. *Constr. Build. Mater.* **2022**, *321*, 126330. [CrossRef]
4. Jamshaid, H.; Hussain, U.; Mishra, R.; Tichy, M.; Muller, M. Turning textile waste into valuable yarn. *Clean. Eng. Technol.* **2021**, *5*, 100341. [CrossRef]
5. Mostaghel, R.; Chirumallab, K. Role of customers in circular business models. *J. Bus. Res.* **2021**, *127*, 35–44. [CrossRef]
6. Lewis, T. Apparel disposal and reuse. In *Sustainable Apparel-Production, Processing and Recycling, First*; Blackburn, R., Ed.; Woodhead Publishing: Cambridge, UK, 2015; pp. 233–248.
7. Niinimamp, K.; Peters, G.; Dahlbo, H.; Perry, P.; Rissanen, T.; Gwilt, A. The environmental price of fast fashion. *Nat. Rev. Earth Environ.* **2020**, *1*, 189–200. [CrossRef]
8. Pensupa, N.; Leu, S.-Y.; Hu, Y.; Du, C.; Liu, H.; Jing, H.; Wang, H.; Lin, C.S.K. Recent trends in sustainable textile waste recycling methods: Current situation and future prospects. *Top. Curr. Chem.* **2017**, *375*, 189–228. [CrossRef]
9. Jaeger, B.; Upadhyay, A. Understanding barriers to circular economy: Cases from the manufacturing industry. *J. Enterp. Inf. Manag.* **2020**, *4*, 729–745. [CrossRef]

10. Galvão, G.D.A.; Evans, S.; Ferrer, P.S.S.; de Carvalho, M.M. Circular business model: Breaking down barriers towards sustainable development. *Bus. Strategy Environ.* **2022**, *31*, 1504–1524. [CrossRef]
11. Hultberg, E.; Pal, R. Lessons on business model scalability for circular economy in the fashion retail value chain: Towards a conceptual model. *Sustain. Prod. Consum.* **2021**, *28*, 686–698. [CrossRef]
12. Das, A.; Konietzko, J.; Bocken, N. How do companies measure and forecast environmental impacts when experimenting with circular business models? *Sustain. Prod. Consum.* **2022**, *29*, 273–285. [CrossRef]
13. Wrålsen, B.; Prieto-Sandoval, V.; Mejia-Villa, A.; O'Born, R.; Hellström, M.; Faessler, B. Circular business models for lithium-ion batteries-Stakeholders, barriers, and drivers. *J. Clean. Prod.* **2021**, *317*, 128393. [CrossRef]
14. Frishammar, J.; Parida, V. Circular Business Model Transformation: A Roadmap for Incumbent Firms. *Calif. Manag. Rev.* **2018**, *61*, 5–29. [CrossRef]
15. Nußholz, J. Circular business models: Defining a concept and framing an emerging research field. *Sustainability* **2017**, *9*, 1810. [CrossRef]
16. Bocken, N.; Short, S.; Rana, P.; Evans, S. A value mapping tool for sustainable business modelling. *Corp. Gov.* **2013**, *13*, 482–497. [CrossRef]
17. Lüdeke-Freund, F.M.; Gold, S.; Bocken, N. A Review and Typology of Circular Economy Business Model Patterns. *J. Ind. Ecol.* **2019**, *23*, 36–61. [CrossRef]
18. Albertsen, L.; Richter, J.L.; Peck, P.; Dalhammar, C.; Plepys, A. Circular business models for electric vehicle lithium-ion batteries: An analysis of current practices of vehicle manufacturers and policies in the EU. *Resour. Conserv. Recycl.* **2021**, *172*, 105658. [CrossRef]
19. Lieder, M.; Rashid, A. Towards circular economy implementation: A comprehensive review in context of manufacturing industry. *J. Clean. Prod.* **2016**, *115*, 36–51. [CrossRef]
20. Masi, D.; Kumar, V.; Garza-Reyes, J.A.; Godsell, J. Towards a more circular economy: Exploring the awareness, practices, and barriers from a focal firm perspective. *Prod. Plan. Control.* **2018**, *29*, 539–550. [CrossRef]
21. Bocken, N.; de Pauw, I.; Bakker, C.; van der Grinten, B. Product design and business model strategies for a circular economy. *J. Ind. Prod. Eng.* **2016**, *33*, 308–320. [CrossRef]
22. Ferasso, M.; Beliaeva, T.; Kraus, S.; Clauss, T.; Ribeiro-Soriano, D. Circular economy business models: The state of research and avenues ahead. *Bus. Strategy Environ.* **2020**, *29*, 3006–3024. [CrossRef]
23. Tukker, A. Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet. *Busin. Strat. Environ.* **2004**, *13*, 246–260. [CrossRef]
24. Tukker, A. Product services for a resource-efficient and circular economy–A review. *J. Clean. Prod.* **2015**, *97*, 76–91. [CrossRef]
25. de Kwant, C.; Rahi, A.B.M.F.; Laurenti, R. The role of product design in circular business models: An analysis of challenges and opportunities for electric vehicles and white goods. *Sustain. Prod. Consum.* **2021**, *27*, 1728–1742. [CrossRef]
26. Clauss, T.; Bouncken, R.B.; Laudien, S.; Kraus, S. Business model reconfiguration and innovation in SMEs: A mixed-method analysis from the electronics industry. *Int. J. Innov. Manag.* **2020**, *24*, 2050015. [CrossRef]
27. Kraus, S.; Clauss, T.; Breier, M.; Gast, J.; Zardini, A.; Tiberius, V. The economics of COVID-19: Initial empirical evidence on how family firms in five European countries cope with the corona crisis. *Int. J. Entrep. Behav. Res.* **2020**, *26*, 1067–1092. [CrossRef]
28. GFIS. Global Fashion Industry Statistics—International Apparel. Available online: https://fashionunited.com/global-fashion-industry-statistics/ (accessed on 6 December 2022).
29. Shirvanimoghaddam, K.; Motamed, B.; Ramakrishna, S.; Naebe, M. Death by waste: Fashion and textile circular economy case. *Sci. Total Environ.* **2020**, *718*, 137317. [CrossRef]
30. Payne, A. Open- and closed-loop recycling of textile and apparel products. In *Handbook of Life Cycle Assessment (LCA) of Textiles and Clothing*, 1st ed.; Muthu, S.S., Ed.; Woodhead Publishing: Sawston, UK, 2015; pp. 103–123.
31. Korhonen, J.; Honkasalo, A.; Seppälä, J. Circular economy: The concept and its limitations. *Ecol. Econ.* **2018**, *143*, 37–46. [CrossRef]
32. VTRc. About the Enterprise: VIVE Textile Recycling. Innovativeness. Available online: https://www.vivetextilerecycling.pl/o-firmie/ (accessed on 4 May 2022).
33. Bocken, N.M.P.; Harsch, A.; Weissbrod, I. Circular business models for the fastmoving consumer goods industry: Desirability, feasibility, and viability. *Sustain. Prod. Consum.* **2022**, *30*, 799–814. [CrossRef]
34. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives (Text with EEA Relevance). Available online: https://www.legislation.gov.uk/eudr/2008/98/contents# (accessed on 25 June 2022).
35. Journal of Laws 2021, Item 779, Art. 31, Para. 23. Available online: https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=NIM:202108114 (accessed on 4 May 2022).
36. VTRe. Responsible Business Appreciated. VIVE Textile Recycling Nominated in the Sustainable Impact Plebiscite. Available online: https://gala.com.pl/odpowiedzialny-biznes-doceniony/ (accessed on 4 May 2022).
37. Chesbrough, H. Business Model Innovation: Opportunities and Barriers. *Long Range Plann.* **2010**, *43*, 354–363. [CrossRef]
38. Ranta, V.; Aarikka-Stenroos, L.; Ritala, P.; Mäkinen, S.J. Exploring institutional drivers and barriers of the circular economy: A cross- regional comparison of China, the US, and Europe. *Resour. Conserv. Recycl.* **2017**, *135*, 70–82. [CrossRef]
39. Saebi, T.; Lien, L.; Foss, N.J. What drives business model adaptation? The impact of opportunities, threats and strategic orientation. *Long Range Plann.* **2017**, *50*, 567–581. [CrossRef]

40. Ünal, E.; Shao, J. A taxonomy of circular economy implementation strategies for manufacturing firms: Analysis of 391 cradle-to-cradle products. *J. Clean. Prod.* **2019**, *212*, 754–765. [CrossRef]
41. Galvão, G.D.A.; Nadae, J.; Clemente, D.H.D.H.; Chinen, G.; de Carvalho, M.M. Circular economy: Overview of barriers. *Procedia CIRP.* **2018**, *73*, 79–85. [CrossRef]
42. Kirchherr, J.; Piscicelli, L.; Bour, R.; Kostense-Smit, E.; Muller, J.; Huibrechtse-Truijens, A.; Hekkert, M. Barriers to the circular economy: Evidence from the European Union (EU). *Ecol. Econ.* **2018**, *150*, 264–272. [CrossRef]
43. Vermunt, D.A.; Negro, S.O.; Verweij, P.A.; Kuppens, D.V.; Hekkert, M.P. Exploring barriers to implementing different circular business models. *J. Clean. Prod.* **2019**, *222*, 891–902. [CrossRef]
44. Breier, M.; Kallmuenzer, A.; Clauss, T.; Gast, J.; Kraus, S.; Tiberius, V. The role of business model innovation in the hospitality industry during the COVID-19 crisis. *Int. J. Hosp. Manag.* **2021**, *92*, 102723. [CrossRef]
45. Evans, S.; Vladimirova, D.; Holgado, M.; Van Fossen, K.; Yang, M.; Silva, E.A.; Barlow, C.Y. Business Model Innovation for Sustainability: Towards a Unified Perspective for Creation of Sustainable Business Models. *Bus. Strategy Environ.* **2017**, *26*, 597–608. [CrossRef]
46. Franceschelli, M.V.; Santoro, G.; Candelo, E. Business model innovation for sustainability: A food start-up case study. *Br. Food J.* **2018**, *10*, 2483–2494. [CrossRef]
47. Shamsuzzaman, M.; Kashem, M.A.; Muhammad Sayem, A.S.; Khan, A.M.; Shamsuddin, S.M.; Islam, M.M. Quantifying environmental sustainability of denim garments washing factories through effluent analysis: A case study in Bangladesh. *J. Clean. Prod.* **2021**, *290*, 125740. [CrossRef]
48. Velu, C. Evolutionary or revolutionary business model innovation through coopetition? The role of dominance in network markets. *Ind. Mark. Manag.* **2016**, *53*, 124–135. [CrossRef]
49. Plano Clark, V.L.; Foote, L.A.; Walton, J.B. Intersecting mixed methods and case study research: Design possibilities and challenges. *Int. J. Mult. Res. Approaches* **2018**, *10*, 14–29. [CrossRef]
50. VTRg. VIVE Textile Recycling Implementation. Available online: https://www.cstore.pl/realizacja-vive/ (accessed on 4 May 2022).
51. Public Holiday. The Polish Parliament Passed on 12 November a Day off from Work. Available online: https://www.pit.pl/aktualnosci/sejm-uchwalil-12-listopada-dniem-wolnym-od-pracy-939740 (accessed on 26 July 2022).
52. VTRd. About the Enterprise: Offer. VIVE PROFIT Stores. Available online: https://www.vivetextilerecycling.pl (accessed on 4 May 2022).
53. VTRh. VIVE Textile Recycling-Technology of Voice Control of Sorting Process. Available online: https://www.youtube.com/watch?v=d9kMeuNFbK4 (accessed on 4 May 2022).
54. VTRm. VIVE PROFIT Chain Stores. Available online: https://www.vivetextilerecycling.pl/40-sklep-sieci-vive-profit/ (accessed on 4 May 2022).
55. VTRa. Ewelina Rozpara Awarded in the Marketing Director of the Year 2019 Competition. 2019. Available online: https://www.vivetextilerecycling.pl/ewelina-rozpara-wyrozniona-w-konkursie-dyrektor-marketingu-roku-2019/ (accessed on 4 May 2022).
56. VTRk. The Vive Profit Brand Focus on Development, Remembering the Responsibility of Business. Available online: https://www.vivetextilerecycling.pl/marka-vive-profit-stawia-na-rozwoj-pamietajac-o-odpowiedzialnosci-biznesu/ (accessed on 4 May 2022).
57. VTRi. VIVE Textile Recycling–Production Line. Available online: https://www.youtube.com/watch?v=yiMFgOvoHjE (accessed on 4 May 2022).
58. CE. Circular Economy Perspectives in the EU Textile Sector. Available online: https://publications.jrc.ec.europa.eu/repository/handle/JRC125110 (accessed on 25 June 2022).
59. Teece, D. Business models, business strategy and innovation. *Long Range Plann.* **2010**, *43*, 172–194. [CrossRef]
60. Journal of Laws 2020, item 433, Chap. 1, Para. 1. Available online: https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20200000433/O/D20200433.pdf (accessed on 23 June 2022).
61. VTRl. We Save the Polish Economy Together. Available online: https://www.vivetextilerecycling.pl/wspolnie-ratujemy-polska-gospodarke/ (accessed on 4 May 2022).
62. Sarkis, J. Supply chain sustainability: Learning from the COVID-19 pandemic. *Int. J. Oper. Prod. Manag.* **2021**, *41*, 63–73. [CrossRef]
63. VTRb. Innovation Appreciated Again. Available online: https://www.vivetextilerecycling.pl/innowacyjnosc-ponownie-doceniona/ (accessed on 4 May 2022).
64. VTRj. VIVE Textile Recycling among the Exhibitors of the Polish Economic Exhibition. Available online: https://www.vivetextilerecycling.pl/vive-textile-recycling-wsrod-wystawcow-polskiej-wystawy-gospodarczej/?lang=en (accessed on 4 May 2022).
65. VTRf. Production Process. Available online: https://www.vivetextilerecycling.pl/proces-produkcji/ (accessed on 4 May 2022).
66. Bouncken, R.B.; Kraus, S.; Roig-Tierno, N. Knowledge- and innovation-based business models for future growth: Digitalized business models and portfolio considerations. *Rev Manag Sci.* **2021**, *15*, 1–14. [CrossRef]
67. Schneider, S.; Spieth, P. Business model innovation: Towards an integrated future research agenda. *Int. J. Innov. Technol. Manag.* **2013**, *17*, 1340001. [CrossRef]

68. McGrath, R.G. Business models: A discovery driven approach. *Long Range Plann.* **2010**, *43*, 247–261. [CrossRef]
69. Cho, T.S.; Hambrick, D.C. Attention as the mediator between top management team characteristics and strategic change: The case of airline deregulation. *Organ. Sci.* **2006**, *17*, 453–469. [CrossRef]
70. Tuggle, C.S.; Schnatterly, K.; Johnson, R.A. Attention patterns in the boardroom: How board composition and processes affect discussion of entrepreneurial issues. *Acad. Manag. J.* **2010**, *53*, 550–571. [CrossRef]
71. Obłój, K. *O Zarządzaniu Refleksje*; MT Biznes Publishing House: Warszawa, Poland, 2007; pp. 91–104.
72. Morris, M.; Schindehutte, M.; Allen, J. The entrepreneur's business model: Toward a unified perspective. *J. Bus. Res.* **2005**, *58*, 726–735. [CrossRef]
73. Zott, C.; Amit, R.H.; Massa, L. The Business Model: Recent Developments and Future Research. *J Manag.* **2011**, *37*, 1019–1042. [CrossRef]
74. Ocasio, W.; Laamanen, T.; Vaara, E. Communication and attention dynamics: An attention-based view of strategic change. *Strateg. Manag. J.* **2018**, *39*, 155–167. [CrossRef]
75. Kraus, S.; Filser, M.; Kailer, N.; Thurner, S.; Puumalainen, K. Business model innovation: A systematic literature review. *Int. J. Innov. Technol. Manag.* **2020**, *17*, 2050043. [CrossRef]
76. Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 Amending Directive 2008/98/EC on Waste (Text with EEA Relevance). Available online: https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX%3A32018L0851 (accessed on 10 June 2022).
77. Lewandowski, M. Designing the business models for circular economy-towards the conceptual framework. *Sustainability* **2016**, *8*, 43. [CrossRef]
78. Chesbrough, H. Business model innovation: It's not just about technology anymore. *Strategy Leadersh.* **2007**, *35*, 12–17. [CrossRef]
79. Reim, W.; Sjödin, D.; Parida, V. Circular business model implementation: A capability development case study from the manufacturing industry. *Bus. Strategy Environ.* **2021**, *30*, 2745–2757. [CrossRef]
80. Jansson, J.; Nilsson, J.; Modig, F.; Hed Vall, G. Commitment to Sustainability in Small and Medium- Sized Enterprises: The Influence of Strategic Orientations and Management Values. *Bus. Strategy Environ.* **2017**, *26*, 69–83. [CrossRef]
81. Urbaniec, M.; Sołtysik, M.; Prusak, A.; Kułakowski, K.; Wojnarowska, M. Fostering sustainable entrepreneurship by business strategies: An explorative approach in the bioeconomy. *Busin. Strat. Environ.* **2022**, *31*, 251–267. [CrossRef]
82. Ritter, T.; Pedersen, C.L. Analyzing the impact of the coronavirus crisis on business models. *Ind. Mark. Manag.* **2020**, *88*, 214–224. [CrossRef]
83. Koźmiński, A.K. *Ograniczone Przywództwo. Studium Empiryczne*; Poltext Publishing House: Warszawa, Poland, 2013; pp. 190, 197–198.
84. Meyer, A.D.; Brooks, G.R.; Goes, J.B. Environmental jolts and industry revolutions: Organizational responses to discontinuous change. *Strat. Manag. J.* **1990**, *11*, 93–110. Available online: http://www.jstor.org/stable/2486672 (accessed on 20 June 2022).
85. Hitt, M.A.; Arregle, J.-L.; Holmes Jr., R.M. Strategic Management Theory in a Post-Pandemic and Non-Ergodic World. *J. Manag. Stud.* **2021**, *58*, 259–264. [CrossRef]
86. Gurd, B.; Helliar, C. Looking for leaders: Balancing' innovation, risk and management control systems. *Br. Account. Rev.* **2017**, *49*, 91–102. [CrossRef]
87. North, D.C. Dealing with a non-ergodic world: Institutional economics, property rights and the global environment. *Duke Environ. Law Pol Forum.* **1999**, *10*, 1–12. Available online: https://hdl.handle.net/10535/3089 (accessed on 7 April 2022).
88. Ahlstrom, D.; Arregle, J.-L.; Hitt, M.A.; Qian, G.; Ma, X.; Faems, D. Managing technological, sociopolitical, and institutional change in the New Normal. *J. Manag. Stud.* **2020**, *57*, 411–437. [CrossRef]
89. Hock-Doepgen, M.; Clauss, T.; Kraus, S.; Cheng, C.-F. Knowledge management capabilities and organizational risk-taking for business model innovation in SMEs. *J. Bus. Res.* **2021**, *130*, 683–697. [CrossRef]
90. Micheli, M.R.; Berchicci, L.; Jansen, J.J.P. Leveraging diverse knowledge sources through proactive behaviour: How companies can use inter-organizational networks for business model innovation. *Creat. Innov. Manag.* **2020**, *29*, 198–208. [CrossRef]
91. Nascimento, D.; Alencastro, V.; Quelhas, O.; Caiado, R.; Garza-Reyes, J.; Rocha-Lona, L.; Tortorella, G. Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. *J. Manuf. Technol. Manag.* **2019**, *30*, 607–627. [CrossRef]
92. Osterwalder, A.; Pigneur, Y.; Tucci, C.L. Clarifying business models: Origins, present, and future of the concept. *Commun. Assoc. Inf. Syst.* **2005**, *16*, 1–25. Available online: https://aisel.aisnet.org/cais/vol16/iss1/1 (accessed on 25 July 2022). [CrossRef]

energies

MDPI

Article

Strategies of European Energy Producers: Directions of Evolution

Jerzy Niemczyk [1], Aleksandra Sus [2], Edyta Bielińska-Dusza [3,*], Rafał Trzaska [1] and Michał Organa [1,*]

[1] Department of Strategy and Management Methods, Faculty of Management, Wroclaw University of Economics and Business, Komandorska 118/120, 53-345 Wrocław, Poland; jerzy.niemczyk@ue.wroc.pl (J.N.); rafal.trzaska@ue.wroc.pl (R.T.)
[2] Department of Management, General Tadeusz Kościuszko Military University of Land Forces, Piotra Czajkowskiego 109, 51-147 Wrocław, Poland; aleksandra.sus@awl.edu.pl
[3] Department of Strategic Analysis, Cracow University of Economics, 31-570 Cracow, Poland
* Correspondence: bielinse@uek.krakow.pl (E.B.-D.); michal.organa@ue.wroc.pl (M.O.); Tel.: +48-36-80-665 (M.O.)

Abstract: The article presents an innovative method of analyzing energy companies' strategies, which aims to identify the strategic orientation of the entities subject to the research and, thus, to initially define the directions of strategic changes in the analyzed sector. The aim of the research, the results of which were used in this publication, was to identify the features of energy sector companies' strategies in the European Union in the period of sector transformation caused by the new climate policy. The analysis area is the energy sector, i.e., the sector whose fundamental strategic goal is energy production. The research used a critical analysis of the subject literature and desk research method with the use of the researchers' own analytical equipment, developed for the needs of this analysis. It was assumed in the conducted research that the primary source of information in the empirical study, the information subject to subsequent analysis, was the analysis of official documents (strategies, financial reports, etc.) posted on the websites of the surveyed corporations. The research results indicate the dominance of the resource-based approach in implementing strategic postulates of the surveyed companies. Nevertheless, the operational activity focuses on the implementation of innovative solutions towards decarbonization and climate neutrality.

Keywords: management; schools of management; planning approach; positional school; resource-based approach to strategy; the innovative and entrepreneurial approach; network organization; energetics; regulated sector; strategy; energy producers

Citation: Niemczyk, J.; Sus, A.; Bielińska-Dusza, E.; Trzaska, R.; Organa, M. Strategies of European Energy Producers: Directions of Evolution. *Energies* **2022**, *15*, 609. https://doi.org/10.3390/en15020609

Academic Editor: Behnam Zakeri

Received: 9 December 2021
Accepted: 8 January 2022
Published: 15 January 2022

1. Introduction

Changes in the energy sector across the world are happening due, inter alia, to political and legal conditions and regulations [1], which have transformed this strategic sector and affected the efficiency of operations that guarantee the proper functioning of the economies of states, countries, and regions. The energy policy of the European Union, its goals, and measures have been subject to profound evolution due to the global energy crises [2], environmental threats [3,4], an increase in the prices of energy resources and electricity prices [5], as well as the economic integration in the European Union [4].

These factors have resulted in the formation of three main groups of energy policy objectives: increasing the economy's competitiveness, maintaining the energy security of EU countries, and the protection of the natural environment against the harmful effects of energy production and supply [2,6]. Importantly, their implementation should include sets of activities at the macro-, meso- and micro-levels.

The economic practice of many highly developed countries shows that social and economic development results from the impact and cooperation of many interdependent groups and the actions of authorities and economic leaders. Moreover, the potential development opportunities of regions increase by conducting an active regional development policy, in line with the adopted strategy of the energy sector [7]. This strategy should take into account the differences of interests, the autonomy of participants, cooperation between them, unforeseen events, and mutual learning resulting from them. On the other hand, its effectiveness will be greater if the aspects of networking, innovation, creativity, and intellectual values are taken into account.

Considering the problem of strategy in the analyzed energy sector, attention should be paid to the importance of the goals hierarchy that determines various types of strategies. The primary strategic documents on which the conducted energy policy is based are EU guidelines [8–17] as well as the long-term and medium-term development strategies of European countries [18], containing significant indications from the perspective of defining development activities. It should be emphasized that the energy policy of the EU countries determines the strategies of the Member States [5]. These strategies, in turn, provide the basis for guiding policy documents at lower levels. However, all EU countries should be precisely considered and analyze their statutory obligation to prepare a document equivalent to the European Union's legal system [3]. The coherence of the goals' hierarchy [19] and the direction of interventions in the field of energy policy is a condition for the effectiveness of these activities. This causes the necessity to redefine and adjust the strategy and actions of all participants [20].

B. Fattouh et al. [21] note that the global energy industry is approaching another energy transformation. The 21st century will be characterized by an increasing share of cost-competitive renewable technologies and a shift away from high-carbon fuels. Critical uncertainty is related to the pace of transformation and its impact on the business strategy of companies and countries.

Therefore, it is essential that the EU tackle the significant energy challenges, setting out an ambitious energy policy that encompasses the full range of energy sources, allowing the transformation of economies to low energy while ensuring greater security, competitiveness, and sustainable energy consumption [5]. However, this means that policy change is transforming the sector [22] and its companies [23–26], who are seeking to align their strategy with top-down guidelines [27], as well as become change agents.

It should be emphasized that one cannot talk about a long-term operation in the energy sector without a clearly defined strategy, which, apart from the tasks mentioned above, also allows the creation of a desired vision of the future. The issue of strategy is critical in the energy sector, as the reliable functioning of this part of the economy is a crucial element of the entire national economy's stability [28].

The area of research on identifying strategies and types of enterprises developed by the energy sector, including those as a result of the adopted EU strategies, environmental conditions, digitization, or climate transformation, is still evolving in the scientific literature [20,24,26–36].

It can be noticed that the strategies of these enterprises are constantly changing, being influenced by global trends and adapting to the turbulent market environment, technology development, and the continually growing social awareness of the energy impact on health and the environment. On the one hand, this requires a new approach to linking the issues of long-term development planning with building the company's strategy. On the other hand, companies must respond to new development directions of the entire sector. To be able to function effectively, these companies must have flexible [21], carefully prepared and implemented development strategies, systematically adapted to the new operating conditions [28] It is also crucial to review strategic priorities more frequently [37].

Despite the great interest in energy transformation and the strategy of companies from the energy sector, we have noticed a research gap in identifying the changes within strategies of these companies concerning the main strategic trends. The insufficient analysis and description of the presented thematic area has also been highlighted by J. Brzóska [31], who believes that in the aspect of the changes taking place in the EU energy sector, energy companies determine their cognitive and utilitarian values in a specific way.

Therefore, the purpose of this publication is to identify the features of the main strategies of the energy sector companies in Western Europe in the period of sector transformation caused by the new climate policy.

This paper is part of a current and relevant scientific discussion. The article's structure consists of the theoretical part in which the evolution of energy policy, the conceptual assumptions of the research approach, and the characteristics of the distinguishing features in selected approaches to the strategy in sectors of energy enterprises are discussed.

The second empirical part presents unique research results along with the application of a critical analysis of the subject literature and desk research with the use of the researchers own analytical equipment, developed for the needs of this analysis. The research part is based on the results of a study focused on 40 corporations. The article ends with conclusions, research limitations, and further research directions.

2. Evolution of Energy Policy

The year 1973 was a turning point for the whole world. The oil crisis, known as the first energy crisis, and the associated increase in oil prices, triggered by the Israeli–Arab war changed the approach to energy resources worldwide. The drastic increase in the price of a crude oil barrel from USD 3 to USD 25 was the beginning of an extensive search for alternative energy sources that could become a guarantee of quasi energy stability. The aforementioned experiences of the first crisis resulted in a focus on the search for new hydrocarbon deposits, the exploitation of known but so far unprofitable oil deposits, and a reduction in liquid fuels' consumption in the power and heating sectors [38]. This trend also accelerated the implementation of nuclear programs and intensified cooperation between highly developed countries, forming, among others, The International Energy Agency (IEA, 1974), the main goal of which was to optimize and increase the energy security of the member states. The second oil crisis (1979–1980) and the Gulf War (1990–1991) were not so dramatic in their consequences thanks to the mechanisms developed, inter alia, by the IEA, supported by the activities of OPEC (Organization of the Petroleum Exporting Countries) [2]. Nevertheless, they made it clear that the possibilities of oil supply were limited and that the time of cheap oil had passed irretrievably, thus triggering the need for economical fuel and energy management [39] and the search for other sources of energy. The oil crises also changed the area of strategic management theory. It was then that M. Porter's concepts appeared, aimed at actions in a situation of market constraints and boiling down to companies creating a strategy mainly as a competitive struggle strategy [40].

Crude oil, including liquefied gas from oil deposits, is one of the primary energy sources. Other non-renewable energy sources are: coal and lignite, bituminous shale and natural bitumens, natural gas, and uranium fuel, which are classified as resources, based on proven recoverable reserves and estimated additional amounts in place. In addition to non-renewable sources, the reserves of which are presented in various studies [41], renewable energy sources began to play a larger role in the global energy economy, namely: hydropower, biomass, wind energy, and geothermal energy, as well as the energy of the sun and sea waves and the thermal energy of the oceans. The depletion of fossil fuel resources, the potential instability of fuel supplies resulting from historical data, as well as the formation of a significant amount of various pollutants during their combustion, which negatively affect the natural environment, has shifted the attention of global economies towards renewable energy sources.

Renewable energy can be defined as "derived from natural repeating processes, obtained from renewable non-fossil energy sources". These energies are an alternative to traditional, non-renewable fossil fuels, and their resources complement each other in natural processes, creating not new but the most current energy from the perspective of contemporary needs and sources of "green" energy [42]. These values are steadily growing, and in the entire European Union, the share of energy from renewable sources increased to

18.9% in 2018 and 19.7% in 2019 (EU-27) [43], and the five EU countries with the highest share of renewable energy in energy consumption are Sweden, Finland, Latvia, Denmark, and Austria.

The latest report on renewable energy appeared in Nature Communications. It presents research on energy consumption in the 42 most important countries in the period from 1980 to 2018. It turns out that wind and solar energy can meet more than 80% of energy needs without storing too much. The study shows that even without energy storage, the countries covered by the analysis would have their energy needs met 72–91% of the time. With proper energy storage, rates would increase to 83–94% [44]. These coefficients differ for the different latitudes of the countries they apply to. In the case of Germany, energy storage is suggested, as well as the combined use of its many sources. Denmark is the undisputed leader in energy from wind farms and Spain from the sun. This is in line with WWF's (World Wildlife Fund) vision, assuming that by 2050 the world will be powered by 100% renewable energy [45].

Such a breakthrough moment for the renewable energy sector's development was the 2015 conference in Paris (COP21), the effect of which was the signing of the Paris Agreement and the commencement of cooperation between countries from all over the world. The agreement's long-term goal is to keep the global average temperature below 2 °C compared to pre-industrial times and take measures to ensure that this index does not exceed 1.5 °C. The agreement came into force on 4 November 2016 upon the ratification of the agreement by at least 55 countries responsible for at least 55% of global greenhouse gas emissions, and it was ratified by all European Union countries [14].

Europe's greatest challenge is to become the world's first climate-neutral continent by 2050. For this purpose, on 11 December 2019, the European Commission presented the European Green Deal, i.e., a set of mechanisms and related activities aimed at the green transformation. Moreover, the document provides for integrating the UN Sustainable Development Goals and defines energy strategies for a safe, sustainable, and low-carbon economy [10]. The European Green Deal is also expected to help end the COVID-19 pandemic. The European Green Deal will be financed by one-third of the EUR 1.8 trillion invested in the NextGenerationEU recovery plan and by the EU's seven-year budget [15].

The year 2020 was a continuation of the world's plans to decarbonize (i.e., reduce the carbon intensity) the world. The number of renewable energy deals has increased as both companies and utility companies prepare to meet climate goals. The consequence of such assumptions will be consolidations throughout the value chain, the improved economic competitiveness of various entities, and an increase in transactional activity in the energy sector: 144 out of 174 mergers and acquisitions since December 2020 concerned assets or companies from the renewable energy sector [46].

3. Conceptual Distinguishing Features of the Research Approach

Strategy is one of the most important management and organizational documents of any organization. It is also, and above all, a way of conduct for the organization's management that is acceptable to the organization's stakeholders. In common understanding, it is synonymous with what is most important in the activities of an organization. At the same time, in formal terms, it is only a selected method of achieving the strategic goal of each organization. In the face of the enormous diversity of conceptual approaches to both the definition of the strategy and the methods of its determination (strategic management schools [28,47–53], it was decided to use the classification presented by J. Niemczyk [40]. The author indicates concepts that allow determining significant boundaries between their key distinguishing features, thus providing a clear distinction of their specific types [40]:

- planning approach to strategy,
- positional approach to strategy,
- resource-based approach to strategy,
- innovative and entrepreneurial approach to strategy,
- network approach to strategy.

The precursor of the analytical approach to strategy was H.I. Ansoff [54], who indicated that strategy consists of synergistic components [55]:

- product and market orientation;
- growth vector indicating the directions of development of companies taking into account product and market positions: (a) market penetration, (b) market development, (c) product development, and (d) diversification;
- isolation of unique opportunities within the product-market orientation and the growth vector, which the author calls competitive advantage.

Together, they create the market path for the organization in its environment. The first describes the scope of the search, the second, their directions, and the third, barriers to entering the market. According to the author, there is a synergy between them, which is the company's measurable ability to generate profits from new product-market orientations. Strategy in the planning approach, along with a detailed specification of organizational goals that H.I. Ansoff was the first to classify into three main groups, distinguishing strategic, administrative, and operational purposes, focuses on issues related to the environment rather than the inside of the organization [55] and is a disciplined and rational process [56]. The distinguishing features of this approach are a strategy adjusted to the environment and oriented at maximizing profits resulting from their proper distribution [40,57]. The strategic plan, which was the basic tool [28], was a consequence of the belief in the predictability and stability of the environment, as well as the accuracy of forecasts and rationality of decisions made.

The development of the positional school in theoretical terms, management science owes to M.E. Porter. However, the foundations of this school can be found in the works of E.H. Chamberlin, who was the first to emphasize monopolistic competition [58]. The essence of the strategy in the positional approach is to achieve a competitive advantage [59], while its basic distinguishing features are the following assumptions: (a) the company's environment is the starting point for building and analyzing the strategy, (b) strategy formulation always takes place in terms of competition, (c) minimization of costs and differentiation determine strategic success, and (d) the recommended size of the organization is small or large [57].

Therefore, the development of the strategy is accompanied by diagnostic tests in the field of the strategic and competitive position of the organization, which results in the organization's transformation, consisting of the optimization of production decisions, inventory management, or coordination of activities [57]. Paradoxically, operational efficiency becomes the strategic goal in the positional trend, and the return on invested capital and income per employee are its basic assumptions [60]. The organization's attention focuses on the following changes [61]:

(a) restructuring, resulting from the slimmer, simplified, and streamlined organization;
(b) redesigning operational processes (reengineering), simplifying and increasing the speed of critical processes;
(c) creating organizational culture: mission, values, and beliefs become clearer and emphasize the need to generate value for the environment: customers and stakeholders;
(d) human resource management: correcting the existing relations with employees to increase the flexibility of work, their participation, and responsibility for the company, and focus on combining motivation with the development of the organization.

In the positional approach, the organization's activities are operationalized, and concepts such as Total Quality Management, benchmarking, time-based competition, and outsourcing are created, which, however, does not lead to a permanent increase in profitability [62]. The most frequently implemented strategies in this trend are the so-called generic strategies: overall cost leadership, differentiation, and focus [63].

The resource-based approach to strategy diminishes the role of the environment in the process of shaping the strategy, and the focus is more on the inside of the organization and its resources and skills. Scientists permanently connected to this trend are E. Penrose, K.

Prahalad, G. Hamel, J.B. Barney, G. Stalk, P. Evans, L.E. Shulman, and J. Kay. However, the origins of this strategic idea should be sought earlier, in the works of I. Ansoff [55], A.D. Chandler Jr. [64], B. Wernerfelt [65], and P. Selznick [66], who introduced the category of "distinctive competence" [67] of the organization into management, contrasting it with the category of "ineptitude".

The leading theories of competitive advantage sources in terms of resources are (a) the core competencies theory by G. Hamel and C.K. Prahalad, (b) the concept of competing based on the company's ability of G. Stalk, P. Evans, and L.E. Shulman, and (c) J. Kay's theory of distinctive abilities. These theories define what types of resources are critical in the process of generating competitive advantage, ways of shaping these resources, and their effective use in a strategic dimension.

Therefore, the company's strategy is focused on building such a bundle of competencies, according to G. Hamel and C.K. Prahalad, which will guarantee the organization's dynamic development using knowledge and learning processes, regardless of organizational boundaries (according to the authors). They pay particular attention to the coordination of employees' skills and the integration of various sources of knowledge (including technology flows), for which the key success factors are communication, commitment, and involvement in organizational processes [68]. In a polemic with G. Hamel and C.K. G. Stalk, P. Evans and L.E. Shulman in the "Harvard Business Review" [69] argued that key competencies in the context of creating a competitive advantage constitute a complex category of resources and skills, and therefore should instead be called "skills" of the company. These, in turn, can be defined as "a set of strategically understandable business processes" [70], which the authors prove by analyzing global organizations (Honda, Wal-Mart, Canon).

R. Amit and P.J. Schoemaker also placed the critical importance of processes, describing "skills" as (iterative) processes and product innovation, production flexibility, responsibility for shaping market trends, and short product development cycles [71]. This approach was developed later by D.J. Teece, G. Pisano, and A. Shuen, giving these skills a dynamic character and defining them as those that enable the company to adapt, integrate, and reconfigure internal and external organizational skills, resources, and competencies [72]. Therefore, dynamic capabilities are the ability to integrate, build, and reconfigure internal and external competencies aimed at the suddenly changing environmental conditions in which these organizations function, the primary sources of which should be sought in microfoundations, individual activities (microactions), and microaspects [72].

In turn, relations and the connected relational capital become determinants of the organization's success, thus permanently occupying an unquestionable place in the theory and practice of strategic management, including the concept on which J. Kay based his conclusions. The author identified three basic distinguishing capabilities of the company, namely the architecture of the organization, the company's reputation, and innovation, making market efficiency dependent on these elements [73]. At the same time, he emphasized that they do not have to co-occur to allow the company to be able to achieve a competitive advantage, and they may not exist at all. In this case, access to strategic resources becomes crucial, replacing the need to have distinctive capabilities (e.g., a license to use a natural resource or having an exclusive right to provide a specific good) [73].

The foundation of the strategy in the innovative and entrepreneurial approach are activities that highlight building a competitive advantage based on the skillful use of fleeting opportunities [57]. They result from the disruptive technologies theory, according to which organizations investing significant financial resources in developing a product based on new technologies cannot maintain a competitive advantage in the long term. The authors of this concept argue that these types of enterprises are doomed to failure for one prosaic reason, namely, they stay too close to their customers. As a result of performance trajectories, progressive product and service cannibalization generates results in the form of customer satisfaction with solutions already known to them [74]. In the case of the energy sector, already in 2013, McKinsey Global Institute emphasized that the renewable energy sector will be such disruptive technologies, and with it the generation of electricity from renewable sources with reduced harmful climate impact, and also advanced oil and gas exploration and recovery, which will make the extraction of unconventional oil and gas economical [75]. This fact was additionally emphasized by the findings at the Paris conference in 2015 and by other studies on the disruptive technologies' impact on the energy sector [76].

In this way, a new business model is implied, the foundation of which is innovation and the implementation of a self-regenerating mechanism for the emergence of market opportunities, which implies the need to apply an innovative strategy. Open innovations taking the form of outside-in (e.g., crowdsourcing) and inside-out (e.g., knowledge sharing in the form of coopetition) strategies are such a tool of the entrepreneurial and innovative trend [77]. Therefore, the changing model of organization development based on the global network caused a change in the value chain of many organizations and resulted in the expansion of the channels of knowledge inflows and outflows [78–80]. Coopetition in the energy sector may seem particularly interesting, mainly due to the fact that it is a sector: (a) regulated and (b) composed of a relatively limited number of market players in individual countries, which is confirmed in the following parts of this study. Nevertheless, the growing importance of coopetition alliances underlines the need for research in the field of value creation achieved by competitive behavior [45], especially when proposed research confirms such systems' creation in Western Europe, regardless of the issue dimensions (locally, in the form of international cooperation, or network cooperation [46], and also in the context of pandemic threats [81].

In addition, due to the growing importance of innovation, an approach that strongly emphasizes the role of innovative solutions in the area of strategy is value innovation. This model aims to minimize costs without having to offer less value to its customers due to giving up competition in existing markets. Value innovation is a strategy covering all areas of the organization, consisting of integrating utility, price, and costs with market pioneering [82].

The newest way to think about strategy is the concept of network organization. The strategy of such an organization will focus on achieving a common goal—not an individual entity goal anymore but a network of individuals connected by common bonds [83], engaged in a long-term relationship [84]. Interactions between organizations are long term, involving exchange, commitment, and reciprocity [85], in terms of resources, actors, and activities, without clearly delineating boundaries and structure [86]. The strength of an entity in the network does not depend on its specific position in imperfect markets but on the links with customers, suppliers, sellers, and competitors, and the very adaptability and the ability to exchange information are critical features of the network according to much of the research [87].

Networks are nowadays slowly becoming the dominant form of economic activity. This is mainly because most of the contemporary organizations notice the undeniable benefits from participation in this type of system. Such a tendency is also driven by a good diagnosis of inter-organizational network functioning mechanisms and increasing awareness of these interaction systems' diversity [88–90].

The analyzed schools and their distinguishing features are shown in Table 1.

Table 1. Differentiators of strategies in selected schools of strategic thinking.

Strategic Approach	Orientation of Strategic Goals	Strategy Differentiators
Planning	financial result and production activities	- dominance in the strategy description with categories such as plan, long-term, production costs, product diversification - building efficiency primarily based on economies of scale and the experience curve - focus on the long-term planning of activities - diversification criteria based on the economy of scale or scope guideline
Positional	increasing market shares, focusing on long-term competitive advantage	- emphasizing categories related to obtaining a competitive advantage in the strategy - building efficiency by increasing market share - domination in the strategy description with categories such as a sector, segment, advantage, entry barriers, risk - diversification criteria based on balancing risk and utility (portfolios)
Resource-based	building the value of the organization in terms of economic value	- highlighting the key competencies in the strategy - domination in the strategy description with categories such as resources, key competencies, value building, KPIs, stakeholders - effectiveness built on financial methods of building value - diversification criteria based on the use of key competencies
Innovative and entrepreneurial	"blue ocean", focusing on actions in the strategy description at the expense of defining strategic goals	- domination in the strategy description with categories such as innovation, processes, intellectual value - diversification criteria based on the guideline to look for sources of innovation or "blue ocean" areas, engaging in coopetition - effectiveness resulting from the continuous generation of product, business, financial, and other innovations
Network	building an ecosystem understood as a network of interdependent and sharing resources and values of the organization	- domination in the strategy description with categories such as network, relations, stakeholders - domination of effectiveness based on building a network of values, using the network effect - diversification criteria based on the use of the network effect, including other customer groups - utilizing the following categories: ecosystem, cluster, service centers, technology parks, franchise

Source: [91] (based on a research proposal by [92]).

4. Research Procedure and the Research Sample Description

The aim of the research, the results of which were used in this publication, was to identify the features of energy sector companies' strategies in the European Union in the period of sector transformation caused by the new climate policy. The analysis area is the energy sector, i.e., the sector whose fundamental strategic goal is energy production. In turn, the strategy was defined as the manner of achieving this strategic goal declared in the company's strategic documents. The strategies of energy producers in the European Union were analyzed, which was a deliberate choice. Here, all producers should already be in the area of the adopted climate policy defined in Paris. Therefore, the article poses the following hypothesis:

Hypothesis 1 (H1). *The strategies of energy producers are evolving towards innovation strategies.*

To confirm this hypothesis, the 1st iteration of the research was conducted using the adopted methodology, the results of which are presented in this article. The subsequent iterations of the study with the proposed method will be carried out in 3 years (2nd iteration) and 6 years (3rd iteration). Thanks to this approach, comparative statements will be obtained, from which it will be possible to finally verify the presented hypothesis. The graphical flowchart for the crucial work steps within the adopted method has been prepared (Figure 1).

The research used a critical analysis of the subject literature and desk research method with the use of researchers own analytical equipment, developed for the needs of this analysis. It was assumed in the conducted research that the primary source of information in the empirical study, information subject to subsequent analysis, would be the analysis of official documents posted on the websites of the surveyed corporations. The first step was to select the research sample. Energy corporations located in the European Union were chosen for the research. During the preliminary procedure, 41 corporations meeting the following criteria were selected:

- the corporation is registered in one of the 10 largest countries in the European Union in terms of population,
- the corporation is one of the largest energy companies in a given country in terms of value, engaged in activities related to energy production.

One organization located in the United Kingdom was selected, despite the fact that in 2020 it left the European Union. Most of the analyzed data concern the period up to 2019, and the influence of British organizations on the EU market is evident. Since, in the case of one of the pre-selected organizations from Romania (Transgex), it was impossible to obtain appropriate data allowing for a proper assessment of the dominant strategic approach, this unit was excluded from the research sample. As a result, a list of 40 corporations (Table 2) was obtained, which were subject to detailed analysis.

Table 2. Research sample *.

Country	Enterprises Analyzed
Germany	RWE AG, ENBW Energie, Siemens Energy, E.ON SE, Thuega Holding
United Kingdom	EDF
France	Engie, Albioma SA, Elec de Strasbrg, Neoen
Italy	Enel, A2a, Acea, ERG, Saras
Spain	Iberdrola, Endesa, Naturgy Energy, Acciona, EDP Renovaveis
Poland	PGE, ENEA, Tauron, Ze Pak, PGNIG
Romania	Societatea natio, Electrica SA
The Netherlands	Photon Energy
Belgium	Tessenderlo Group, Picanol
Greece	Public Power Corp, Mytilineos SA, GEK Terna Holding, Terna Energy, Karatzis SA, PPC Renewables
Czech Republic	CEZ AS, Energo-PRO, EP Energy, E4U

* Countries by population, companies by Market Capitalization (highest first). Source: own research based: Bloomberg industry Classification Standard [93].

The next step was to verify the availability and timeliness of the information on the strategy on the websites of individual corporations. The research assumption was the analysis of the facts as of 1 October 2021. The next stages of the research were carried out in accordance with the descriptions contained in Figure 1. The research procedure was based on the methodological guidelines included in the study by J. Niemczyk and J. Jurczyk [94].

In line with the previously adopted assumption, this study uses selected approaches to the strategy, and their summary is presented in Section 3 of this study. The analytical approach used in the paper assumes conducting a study of the energy corporations' strategies based on the adjustment of the expressions used for the purposes of strategy formulation and the epistemology of description to a specific strategic approach implemented in economic practice.

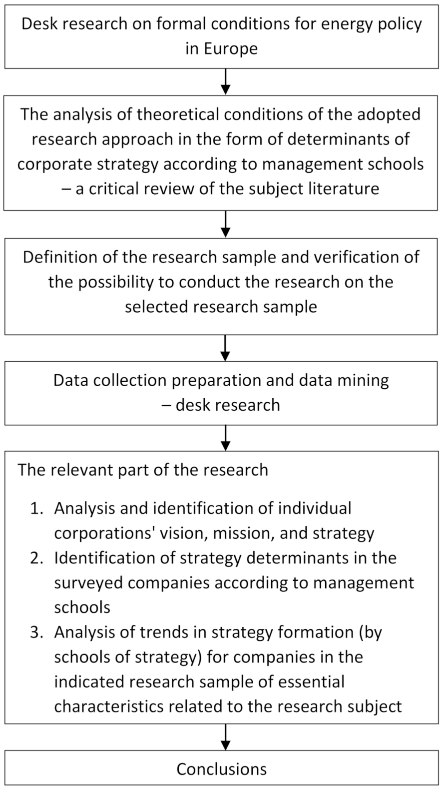


Figure 1. Planned work steps of the conducted study.

5. Results

The interpretation of the research results after the desk research procedure, with the use of the previously described, in-house analytical apparatus, allows for the unequivocally negative verification of the hypothesis adopted in this article: "the strategies of energy producers are evolving towards innovation strategies". According to the summary presented in Figure 2, the dominant strategic approaches in the activity of the 40 surveyed companies of the European energy sector, declared in the formal strategic documents, as well as in the vision, mission, and organizational values, and in the implemented system of strategic goals, are primarily the resource-based approach (exactly 50% of the analyzed entities) and the innovative and entrepreneurial approach (32.5%). The dominance of the positional approach to strategy was found in only five organizations (12.5%) and the network approach to strategy in only two of them (5%). It is also worth noting that with the applied analytical apparatus, no dominance of the planning approach to strategy was found in any of the studied entities.

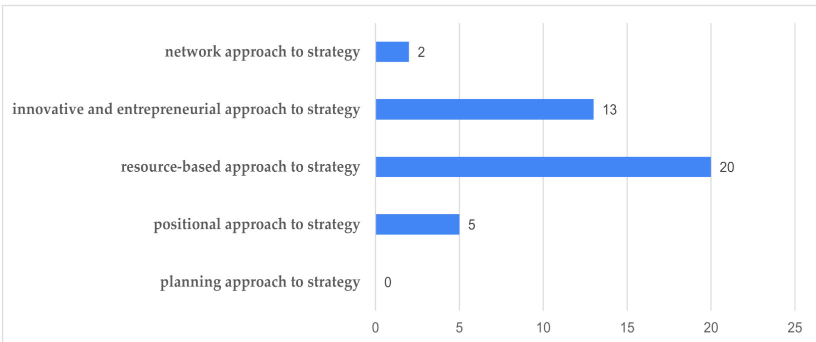


Figure 2. Prevalence of dominant strategic approach types among the researched European corporations from the energy sector (source: own elaboration).

It is worthwhile analyzing the observed phenomenon in a little more detail. For this reason, the considered distribution of the dominant strategic approaches in relation to the individual countries in which the analyzed organizations from the energy sector operate is presented in Table 3. The analysis of the indicated table enables further conclusions to be reached, based on several criteria.

Table 3. Prevalence of dominant strategic approach types among the researched European corporations from the energy sector concerning individual countries (source: own elaboration).

Country	Planning Approach to Strategy	Positional Approach to Strategy	Resource-Based Approach to Strategy	Innovative and Entrepreneurial Approach to Strategy	Network Approach to Strategy	Total Number of Analyzed Enterprises within Country
Germany	0	1	0	3	1	5
United Kingdom	0	0	1	0	0	1
France	0	1	1	2	0	4
Italy	0	0	5	0	0	5
Spain	0	0	2	2	1	5
Poland	0	0	4	1	0	5
Romania	0	2	0	0	0	2
The Netherlands	0	0	0	1	0	1
Belgium	0	0	0	2	0	2
Greece	0	1	3	2	0	6
Czech Republic	0	0	4	0	0	4
In total	0	5	20	13	2	40

One of the criteria used to analyze the achieved results may be the broadly understood level of development of individual countries. Chronologically, the most recent approach to strategy, the network approach, is represented to a small extent by the energy sector organizations under study. This may result from a lack of knowledge or awareness of operating in network structures and conditions by individual entities of modern business. Additionally, the aversion to declaring potentially unrecognized concepts as key values for the strategy of a particular organization may in this case constitute a real barrier to the popularization of this approach. However, it is represented by two of the analyzed companies, which conduct their activities in advanced economies (Germany and Spain).

In addition, the innovative and entrepreneurial approach to strategy is mostly represented by such economically advanced countries (e.g., Germany, France, Spain, Belgium, The Netherlands). It is worth using specific rankings to organize considerations. An example of such a ranking may be the World Competitiveness Ranking prepared by the International Institute for Management Development (IMD), which is primarily based on the categories of innovation, digitalization, welfare benefits, and social cohesion ranks in particular countries, comparing their overall competencies in achieving long-term value creation [95]. Indications for particular countries, according to the mentioned World Competitiveness Ranking, are presented in Table 4.

Table 4. Position of considered countries in the World Competitiveness Ranking.

	The Netherlands	Germany	United Kingdom	Belgium	France	Czech Republic	Spain	Italy	Greece	Poland	Romania
2021 position	4	15	18	24	29	34	39	41	46	47	48
comparison to 2020	no change	+2	+1	+1	+3	−1	−3	+3	+3	−8	+3

Source: [95].

The resource-based approach to strategy, due to its highest frequency of occurrence, is represented by European countries that are diverse in terms of development. It is worth noting, however, that most of the indications in this area are given by countries that occupy lower positions in the aforementioned International Institute for Management Development (IMD) ranking in Europe. This is the case for Italy, Greece, and Poland, for which a total of 12 out of 20 indications were noted in the strategic documents of individual companies under consideration. It is also worth emphasizing that the high total number of references to resource issues may be related to a good, firmly rooted recognition of these categories, both in the scientific area and in business practice.

The positional approach, in turn, in several cases was found to be dominant both among companies from countries considered to be among the most developed (Germany), but also among entities operating in countries not belonging to the European economical top rank (Romania). This may prove the universality of strategy consideration in the already very well-established concept of the systematic building of position and competitive advantage in the environment of the energy sector organization.

What is slightly surprising is the lack of identification of expressions of the planning approach in the strategic materials of the surveyed organizations. Some justification for this may be the complete absorption of this approach by other approaches as an integral set of distinctions and guidelines. In such a situation, the concept of strategy as a long-term plan of action, of course, does not have to be negated, and in principle is recognized as a natural and basic feature of all other approaches.

The indicated results of the conducted desk research analysis, despite the observation of significant and clear conclusions, may seem somewhat blurred and ambiguous, which the authors of this study are aware of. Increasing the precision of indications would require extending the research scope, both in terms of geographical range (subsequent countries included in the analysis), as well as increasing the research sample. However, there are clear barriers in this case, primarily in the form of a limited number of corporations from the sector under consideration, which is related to the specificity of the activity and significant initial requirements for its initiation.

The relatively popular recent criterion of the use of fossil fuels compared to renewable energy sources also does not provide a clear dividing key in the case under consideration between the strategy approaches used by the organizations under study. Data on this issue for 2019, presented in Table 5, confirm that the current use of fossil fuels (as a share of total energy demand and gross available energy) in almost all countries considered clearly exceeds 72–73%. A significantly lower indicator is shown in this case by France (level of only 49.63%). However, for this country, no exceptionally different approach to the strategy was identified. On the basis of the analysis carried out, it was concluded that the French energy companies under consideration show quite diverse inclinations in this respect, presenting elements of positional, resource, or innovation–entrepreneurial approaches in their strategy documents. At the other end of the scale is The Netherlands (with a level of use of fossil fuels currently at 92.4%). One company reviewed for this country was found to be dominated by an innovative and entrepreneurial approach to strategy. The Netherlands itself is seen as one of the most developed countries in the world (according to the previously presented World Competitiveness Ranking by IMD, with the fourth position in the global scale, which should be considered as really outstanding).

In addition, it is worth analyzing the scale of total energy supply in each of the countries analyzed, as the share of a particular type of energy in total consumption is a relative value and may be unreliable. The analysis of Table 6 shows that for the countries with the largest total energy supplies (in 2019): Germany (almost 3.5 million Gigawatt hours), France (2.85 million GWh), United Kingdom (1.98 million GWh), Poland (1.19 million GWh), or Italy (1.76 million GWh), there is a whole spectrum of approaches to strategies in line with the adopted differentiators. Similarly, for the countries with low energy supply (2019): Greece (only 260.76 thous. GWh), Romania (384.4 thous. GWh), or Czech Republic (495.17 thous. GWh), there is a wide variation in the adopted research sample.

Table 5. Share (%) of fossil fuels in gross available energy.

Country/Year	2012	2013	2014	2015	2016	2017	2018	2019
European Union-28 countries (2013–2020)	75.66	74.83	73.69	73.73	74.00	74.07	73.36	72.36
Euro area-19 countries (from 2015)	74.26	73.48	72.35	72.82	73.19	73.44	72.59	71.67
Belgium	75.45	74.98	76.35	78.90	74.62	75.22	79.05	75.58
Czechia	76.97	75.97	75.00	76.24	77.25	75.97	75.15	73.59
Germany	81.51	82.01	81.32	81.46	82.26	82.22	81.35	79.81
Greece	90.99	89.16	87.38	85.83	86.36	86.99	85.86	84.56
Spain	77.29	75.00	73.99	75.47	74.24	75.97	75.20	74.14
France	51.44	50.95	48.97	49.25	50.29	50.89	49.27	49.63
Italy	83.47	81.32	80.05	80.81	81.34	80.18	79.30	79.26
The Netherlands	93.63	93.78	93.49	93.67	94.01	93.93	92.85	92.40
Poland	91.36	91.58	90.57	90.50	90.97	91.21	90.95	89.60
Romania	76.50	73.99	73.31	73.89	73.07	74.08	74.13	72.88
United Kingdom	87.73	86.34	85.21	82.88	82.49	81.72	80.93	79.97

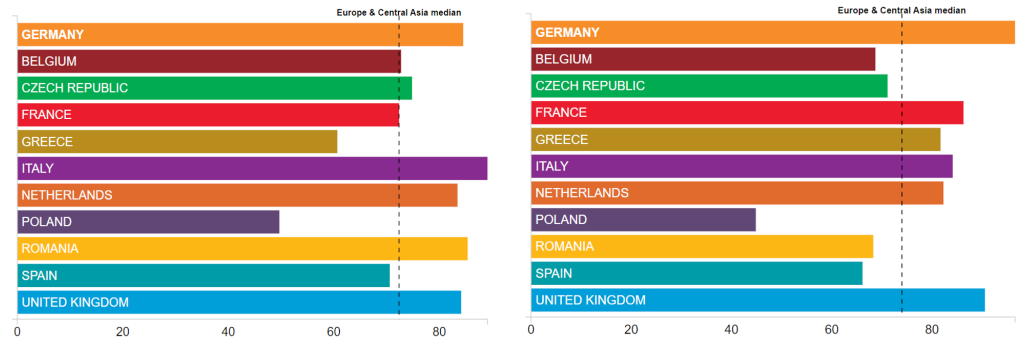
Source: [96].

Table 6. Total energy supply (Gigawatt hours, GWh) in analyzed EU countries.

Country/Year	2012	2013	2014	2015	2016	2017	2018	2019
European Union-28 countries (2013–2020)	19,224,084	19,012,442	18,286,601	18,545,240	18,633,766	18,924,096	18,757,283	18,409,000
Euro area-19 countries (from 2015)	13,585,842	13,474,859	12,955,422	13,156,963	13,201,076	13,394,572	13,206,699	12,970,036
Belgium	624,268	650,421	613,135	611,763	648,135	645,423	621,887	640,497
Czechia	499,492	501,981	485,202	485,637	480,821	501,342	502,753	495,170
Germany	3,668,575	3,749,984	3,588,473	3,606,259	3,621,710	3,633,969	3,547,578	3,470,406
Greece	309,403	272,084	270,011	270,568	264,883	272,235	264,566	260,756
Spain	1,456,625	1,360,061	1,330,591	1,382,227	1,395,918	1,467,576	1,462,923	1,419,784
France	3,015,694	3,031,666	2,913,078	2,959,547	2,907,522	2,907,611	2,894,374	2,853,153
Italy	1,876,388	1,807,187	1,706,934	1,774,311	1,755,918	1,815,367	1,781,190	1,761,528
The Netherlands	897,785	879,455	830,139	844,824	862,212	870,812	853,243	836,899
Poland	1,131,066	1,139,408	1,095,992	1,107,401	1,161,829	1,213,881	1,231,309	1,188,539
Romania	405,322	368,700	364,934	367,900	366,396	386,100	389,079	384,402
United Kingdom	2,220,056	2,182,232	2,054,230	2,093,441	2,062,805	2,030,282	2,023,904	1,983,384

Source: [97].

The criterion of alignment with specific strategic approaches can also be adopted as the degree of internal national regulations supporting or hindering the efficient development of the energy sector. In Figure 3, some comparisons between analysed countries were presented (the higher the score, the more favorable the regulations), on the basis of which certain discrepancies can be observed already in the internal perspective (scale of the domestic market). Based on this criterion, however, it is difficult to identify a reproducible key for matching the strategies of companies from individual countries with selected strategy approaches.



(**a**) (**b**)

Figure 3. Comparing "GCI 4.0: Energy efficiency regulation" indicators with "GCI 4.0: Renewable energy regulation" indicators in analyzed EU countries in 2019: (**a**) GCI 4.0: Energy efficiency regulation indicators—assessments for chosen countries' policies and regulations for energy efficiency energy promotion (0—means "not conducive: 100—means "very conducive"); (**b**) GCI 4.0: Renewable energy regulation indicators—assessments for chosen countries' policies and regulations for renewable energies promotion (0—means "not conducive: 100—means "very conducive"). Source: [98,99].

The last of the criteria selected by the authors of this article for matching the strategies of the surveyed companies to specific strategic approaches is differentiation in terms of the "Energy Transition Index" (ETI) indicator, prepared by the World Economic Forum. This factor is based on previous analyses from the "Global Energy Architecture Performance Index" series, but, in this case (focusing on comparisons of 115 countries), the perspective aspect of the real readiness of a particular country to implement the energy transition was added, taking into account the actual level of the energy systems' performance, and the current readiness of the macro environment for the transition to a stabilized, secure, sustainable, and affordable energy system of the future [100]. This indicator is presented in Table 7. The higher the value of the indicator, the better prepared the energy sector in a given country is for the challenges of the future. The ETI indicator provides a good basis for comparison in the context of ongoing changes in the Industry 4.0 perspective. The 11 countries selected for the study by the authors of this article were arranged in two categories, Emerging and Developing Europe (with only Poland and Romania indicated here) and Advanced Economies (the rest of analyzed countries).

Table 7. Position of considered countries in the perspective of Energy Transition Index, ETI.

	United Kingdom	France	The Netherlands	Belgium	Germany	Spain	Italy	Romania	Czech Republic	Greece	Poland
2020 position	7	8	9	18	20	24	26	35	42	59	69
Transition readiness	68%	64%	68%	64%	64%	59%	56%	52%	56%	47%	48%

Source: [101].

The analysis of the results generated in the course of the desk research procedure described above clearly indicates the difficulty of unambiguously attributing the strategies of the surveyed companies to specific strategic approaches (adopted on the basis of the characteristics indicated in Table 1 in Section 3 of this paper. This is because it is extremely difficult to determine authoritative criteria (from among the following considered: general level of competitiveness of a given economy, share of fossil fuel use in total energy use, size of energy supply, energy efficiency regulation levels vs. renewable energy regulation levels, Energy Transition Index, ETI).

6. Discussion

Enterprises are an integral part of the external and internal conditions that determine their development, which in turn depends on introducing positive strategic changes allowing for adaptation to the changes taking place. Strategic management is also subject to transformations resulting from different views on its essence, e.g., methodological, axiological, or epistemological. The result is the emergence of new approaches, schools of strategy, and an attempt to organize and classify them, confirming the complexity and multidimensionality of this problem. As noted [102], having a wide range of different approaches to strategy, the company's management can choose the one that best suits the company's specificity and its environment. The desire to maintain the development potential and competitiveness in the long term forces the perception of the strategy as a dynamic process of overcoming difficulties and/or taking advantage of opportunities. Thus, the energy transformation, conditioned by several factors, may affect the change of companies' strategy from the energy sector and, consequently, the choice of methods of operation assigned to the main strategic trends.

The analytical approach used in the paper has allowed for conducting a study of the strategies in the European Union's energy corporations' during the period of sector transformations, aiming to identify the strategic features of these companies. Empirical research also allows for the unambiguously negative verification of the article's hypothesis "the strategies of energy producers are evolving towards innovation strategies". The results of this study have several potentially significant observations.

Firstly, the European energy sector companies declare in the formal strategic documents and the implemented system of strategic goals, that the companies' approaches are primarily determined by the resource-based (50%), as well as the innovative and entrepreneurial (32.5%) schools, meaning that these schools are well-known and well-established, in theory and in practice. This implies that managers of this sector should pay particular attention to the activities in these areas.

Secondly, the positional approach to strategy was found in 12.5% of organizations and the network approach to strategy in only 5% of them. Our research shows that the presence of the positional approach proves its importance in building a strategy that takes into account the achievement of competitive advantage in the sector.

However, the network approach, which is the most recent approach to strategy, has been represented to a small extent by the energy sector organizations under this study. In light of the obtained results and theoretical indications, the low popularity of the network approach to strategy may be related to it being a relatively new one. However, the importance of this approach is indicated by studies [103,104]. Nevertheless, [105] notes that management strategies with respect to a networked organization are chosen based on an assessment of access to critical resources and competencies, and in the context of internal and external relationships with other network participants and requires activation of all network participants, exploiting the combined potential and enhancing the cohesion.

The last significant observation concerns the lack of the planning approach to strategy, as no implementation of it was found in studied entities. It may be that this approach was absorbed by others as an integral set of its distinctions and guidelines, as well as the diminishing role of planning, the lack of unambiguous references in the analyzed documents, or a shift to resource-based/innovative strategic approaches, which would be a manifestation of a new way of thinking and a response to changes. However, there is research emphasizing the importance of planning as a strategic approach in the energy sector [28]. Overall, we believe that the strategies of the surveyed companies will continue to develop, and that the innovative and entrepreneurial strategies and inter-organizational relations, especially in network systems, will become particularly important. Hence, the indications are to continue research taking into account these essential areas.

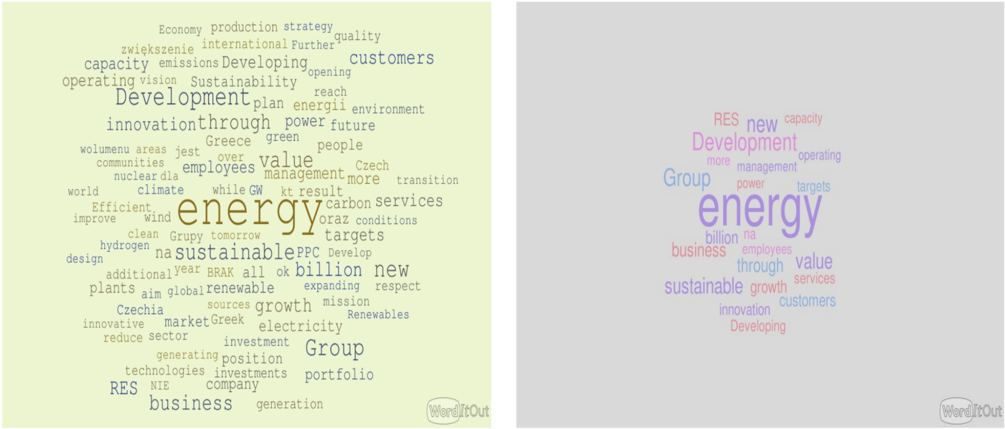
The conducted analytical procedure was based mostly on the appropriate understanding of the statements included in the documents and descriptions of a strategic nature presented by the researched organizations, and assigning them to particular approaches to strategy on the basis of the adopted set of distinctions presented in Table 1. The subjectivity of the realised assessment clearly affected the meaning of the quality of semantic analysis, also significantly conditioning the obtained results. In order to increase the objectivity of the analytical apparatus used, in the future it would be advisable to consider further formalising the assessment procedure and perhaps introducing the principle of parallel assessment of strategic materials by the research team in relation to individual organizations, with an assumed discussion until a consensus is reached. The obvious disadvantage of such an assumption is that it significantly increases the time-consumption and complexity of the planned procedure.

7. Conclusions

The conducted research proves that the dominant strategy of energy companies located in the European Union (40 examined entities) is the resource-based approach. This conclusion allows the rejection of the hypothesis formulated in the article that the strategies of energy producers are evolving towards innovation. This is all the more surprising as, in the face of changes caused by the evolution of energy policy, they should focus on applying innovative solutions and not building the organization's value in terms of economic value. This situation most likely results from the implementation of operational goals, which are focused on implementing innovative solutions, but a consistent description of the strategy in the language of resources.

Changes in energy companies are tangible and visible; after all, they include product, technological, and process solutions that are highly innovative. Such solutions include economic energy installations, the construction of wind and photovoltaic farms, energy storage, and others, with the general purpose of decarbonizing the natural environment. Their implementation is possible due to energy companies' resource concentration in the European Union. This means that focusing on the value generated by human, financial, material, and information resources is still a guarantee of stable growth and strategic development. However, this assumes potential differences in operational goals of various energy companies, considering changing nature of these resources in particular entities.

Based on the analytical procedure described in this paper, frequently occurring words and terms were selected from the strategic materials developed by selected companies in the European energy sector. This set of key words is presented in Figure 4 and can serve as a prelude to further, extended semantic analysis including extended sets of key words to precisely match specific strategic documents, missions, visions, values, and goal systems with specific strategic approaches.



(**a**) (**b**)

Figure 4. Description: (**a**) Word clouds of words and expressions words that appeared at least 5 times; (**b**) Word clouds of words and expressions words that appeared at least 10 times (source: own elaboration with the use of "WordItOut" [106].

Author Contributions: Conceptualization, J.N., A.S., E.B.-D., R.T. and M.O.; methodology, J.N., A.S., E.B.-D., R.T. and M.O.; software, J.N., A.S., E.B.-D., R.T. and M.O.; validation, J.N., A.S., E.B.-D., R.T. and M.O.; formal analysis J.N., A.S., E.B.-D., R.T. and M.O.; investigation, J.N., A.S., E.B.-D., R.T. and M.O.; resources, J.N., A.S., E.B.-D., R.T. and M.O.; data curation, J.N., A.S., E.B.-D., R.T. and M.O.; writing—original draft preparation, J.N., A.S., E.B.-D., R.T. and M.O.; writing—review and editing, J.N., A.S., E.B.-D., R.T. and M.O.; visualization, J.N., A.S., E.B.-D., R.T. and M.O.; supervision, J.N., A.S., E.B.-D., R.T. and M.O.; project administration, J.N., A.S., E.B.-D., R.T. and M.O. All authors have read and agreed to the published version of the manuscript.

Funding: The research has been carried out as part of a research initiative financed by the Ministry of Science and Higher Education within "Regional Initiative of Excellence" Program for 2019–2022. Project no.: 021/RID/2018/19. Total financing: 11,897,131.40 PLN.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: The research team would like to thank Jerzy Niemczyk, long-standing Head of the Department of Strategy and Management Methods at the Wrocław University of Economics, for his conceptual, substantive, and formal support, both in the development of this article and other works written jointly.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Leszczyńska, A.; Lee, K.-H. Sources and barriers of the energy efficiency of polish enterprises. *Ann. Univ. Mariae Curie Skłodowska Sect. H Oecon.* **2016**, *50*, 105–116. [CrossRef]
2. Pach-Gurgul, A. Główne determinanty wahań cen ropy naftowej na świecie na przełomie lat 2014/2015. *Pr. Kom. Geogr. Przemysłu Pol. Tow. Geogr.* **2016**, *30*, 185–198. [CrossRef]
3. Malko, J. Uwarunkowania polskiej polityki energetycznej. *Polityka Energetyczna* **2009**, *12*, 369–391.
4. Lelek, L.; Kulczycka, J. Life cycle modelling of the impact of coal quality on emissions from energy generation. *Energies* **2020**, *13*, 1515. [CrossRef]
5. Miciuła, I. Polityka energetyczna Unii Europejskiej do 2030 roku w ramach zrównoważonego rozwoju. *Studia Pr. Wydziału Nauk Ekon. Zarządzania* **2015**, *42*, 57–69. [CrossRef]
6. Morata, F.; Sandoval, S.I. *European Energy Policy*; Edward Elgar: Northampton, UK, 2012.
7. Sperling, K.; Arler, F. Local government innovation in the energy sector: A study of key actors' strategies and arguments. *Renew. Sustain. Energy Rev.* **2020**, *126*, 109837. [CrossRef]

8. European Commission. Analysis of Options to Move Beyond 20% Greenhouse Gas Emission Reductions and Assessing the Risk of Carbon Leakage. 2010. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52010DC0265&from=EN/ (accessed on 10 November 2021).
9. European Commission. A Roadmap for Moving to A Competitive Low Carbon Economy in 2050. COM(2011) 112 Final. 2011. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0112:FIN:EN:PDF (accessed on 10 November 2021).
10. European Commission. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, The European Green Deal. 2019. Available online: https://www.eea.europa.eu/policy-documents/communication-from-the-commission-to-1 (accessed on 10 November 2021).
11. European Commission. A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. 2015. Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:1bd46c90-bdd4-11e4-bbe1-01aa75ed71a1.0001.03/DOC_1&format=PDF (accessed on 10 November 2021).
12. European Commission. Energy Efficiency and Its Contribution to Energy Security and the 2030 FRAMEWORK for Climate and Energy Policy. 2014. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52014DC0520 (accessed on 10 November 2021).
13. European Commission. Environment New Policy Package to Clean Up Europe's Air. 2013. Available online: https://ec.europa.eu/commission/presscorner/detail/en/IP_13_1274 (accessed on 10 November 2021).
14. United Nations. Nationally Determined Contributions under the Paris Agreement. 2021. Available online: https://unfccc.int/sites/default/files/resource/cma2021_08_adv_1.pdf (accessed on 10 November 2021).
15. European Commission. Stepping Up Europe's 2030 Climate Ambition. Investing in a Climate-Neutral Future for the Benefit of Our People. 2020. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0562 (accessed on 10 November 2021).
16. European Parliament. Energy Policy: General Principles. Fact Sheets on the European Union—2021. Available online: https://www.europarl.europa.eu/ftu/pdf/en/FTU_2.4.7.pdf (accessed on 10 November 2021).
17. Zajączkowska, M. Polityka energetyczna Unii Europejskiej. *Zesz. Nauk. Uniw. Ekon. Krakowie* **2011**, *852*, 81–95.
18. Molo, B. "Wspólna" polityka energetyczna w kontekście tendencji dezintegracyjnych Unii Europejskiej. *Krak. Studia Międzynarodowe* **2017**, *XIV*, 87–105.
19. Stuglik, J. Znaczenie spójności zarządzania strategicznego w przedsiębiorstwach sektora paliwowo-energetycznego ze strategią bezpieczeństwa energetycznego kraju. *Wiert. Naft. Gaz* **2009**, *26*, 383–389.
20. Sulich, A.; Sołoducho-Pelc, L. Renewable energy producers' strategies in the Visegrád group countries. *Energies* **2021**, *14*, 3048. [CrossRef]
21. Fattouh, B.; Poudineh, R.; West, R. The rise of renewables and energy transition: What adaptation strategy exists for oil companies and oil-exporting countries? *Energy Transit.* **2019**, *3*, 45–58. [CrossRef]
22. Ehrenhalt, W. Kierunki transformacji polskiej energetyki. *Energetyka Społeczeństwo Polityka* **2019**, *8*, 88–103. [CrossRef]
23. Shojaeddini, E.; Naimoli, S.; Ladislaw, S.; Bazilian, M. Oil and gas company strategies regarding the energy transition. *Prog. Energy* **2019**, *1*, 012001. [CrossRef]
24. Pickl, M.J. The renewable energy strategies of oil majors—From oil to energy? *Energy Strat. Rev.* **2019**, *26*, 100370. [CrossRef]
25. Zhong, M.; Bazilian, M.D. Contours of the energy transition: Investment by international oil and gas companies in renewable energy. *Electr. J.* **2018**, *31*, 82–91. [CrossRef]
26. Stevens, P. International oil companies. The death of the old business. In *Energy, Environment and Resources*; Chatnam House: London, UK, 2016.
27. Sulich, A.; Grudziński, A. The analysis of strategy types of the renewable energy sector. *Acta Univ. Agric. Silvic. Mendel. Brun.* **2019**, *67*, 1643–1651. [CrossRef]
28. Stós, K. Strategia a długofalowy rozwój przedsiębiorstwa energetycznego. *Polityka Energetyczna* **2009**, *12*, 79–91.
29. Loknath, Y.; Azeem, B.A. Green management—Concept and strategies. In Proceedings of the National Conference on Marketing and Sustainable Development, 13–14 October 2017; pp. 1–15. Available online: https://www.aims-international.org/myconference/cd/PDF/MSD4-6111-Done.pdf (accessed on 23 November 2021).
30. Grudziński, A.; Sulich, A. Strategic goals of renewable energy sector. In Proceedings of the 16th Students' Science Conference "Science Is Our Universe, Oficyna Politechniki Wrocławskiej, Boguszów-Górce, Poland, 19–22 September 2018; pp. 36–44.
31. Brzóska, J. *Modele Strategiczne Przedsiębiorstw Energetycznych*; Wydawnictwo Politechniki Śląskiej: Gliwice, Poland, 2007.
32. Booth, A.; Smith, N. Digital Transformation in Energy: Achieving Escape Velocity. 2020. Available online: https://www.mckinsey.com/industries/oil-and-gas/our-insights/digital-transformation-in-energy-achieving-escape-velocity (accessed on 30 November 2021).
33. Borowski, P.F. Digitization, digital twins, blockchain, and industry 4.0 as elements of management process in enterprises in the energy sector. *Energies* **2021**, *14*, 1885. [CrossRef]
34. Trzaska, R.; Sulich, A.; Organa, M.; Niemczyk, J.; Jasiński, B. Digitalization business strategies in energy sector: Solving problems with uncertainty under industry 4.0 conditions. *Energies* **2021**, *14*, 7997. [CrossRef]

35. Burlat, C.; Mills, C. Power to the people? How an energy company's strategic texts constitute the company-consumer interface working against collective action. *M@n@gement* **2018**, *21*, 738–772. [CrossRef]
36. De Abreu, M.C.S.; de Freitas, A.R.P.; Rebouças, S. Conceptual model for corporate climate change strategy development: Empirical evidence from the energy sector. *J. Clean. Prod.* **2017**, *165*, 382–392. [CrossRef]
37. Johnston, D.; Uro, J. How Energy Companies Can Approach Strategy to Thrive Amid Change. EY-Global. 2021. Available online: https://www.ey.com/en_gl/strategy/how-energy-companies-can-approach-strategy-to-thrive-amid-change (accessed on 30 November 2021).
38. Międzynarodowy Rynek Ropy Naftowej-Charakterystyka Okresów Kryzysowych. Available online: https://www.cire.pl/publikacje/KRYZYSY-NAFTOWE.pdf (accessed on 28 November 2021).
39. Rechul, H. Rozwój światowego i polskiego sektora energii. *Wokół Energetyki* **2005**, *8*, 1–7.
40. Niemczyk, J. *Strategia. Od Planu do Sieci*; Wydawnictwo Uniwersytetu Ekonomicznego we Wrocławiu: Wroclaw, Poland, 2013.
41. Soliński, J. *Sektor Energii—Świat i Polska, Rozwój 1971–2000, Perspektywy do 2030r. / Energy Sector—World and Poland, Development 1971–2000, Prospects to 2030*; Polski Komitet Światowej Rady Energetycznej, Polish Member Committee of the World Energy Council, World Energy Council: Warsaw, Poland, 2004.
42. GUS. *Energia ze Źródeł Odnawialnych w 2014*; PGłówny Urząd Statystyczny: Warsaw, Poland, 2015. Available online: https://stat.gov.pl/obszary-tematyczne/srodowisko-energia/energia/energia-ze-zrodel-odnawialnych-w-2014-roku,3,9.html (accessed on 23 November 2021).
43. Explained EUROSTAT Statistics. Renewable Energy Statistics. 2020. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics#Share_of_renewable_energy_almost_doubled_between_2004_and_2018 (accessed on 26 November 2021).
44. Odnawialne Źródła Energii? Naukowcy Nie Mają Wątpliwości—To Opłacalne i Praktyczne. 2021. Available online: https://www.cire.pl/artykuly/serwis-informacyjny-cire-24/odnawialne-zrodla-energii-naukowcy-nie-maja-watpliwosci---to-oplacalne-i-praktyczne (accessed on 28 November 2021).
45. Singer, S. The Energy Report. 100% Renewable Energy by 2050. Available online: https://wwfeu.awsassets.panda.org/downloads/101223_energy_report_final_print_2.pdf (accessed on 28 November 2021).
46. Deloitte. 2021 Renewable Energy Industry Outlook. Available online: https://www2.deloitte.com/nl/nl/pages/energy-resources-industrials/articles/renewable-energy-industry-outlook.html (accessed on 28 November 2021).
47. Stabryła, A. *Zarządzanie Strategiczne w Teorii i Praktyce Firmy*; PWN: Warsaw, Poland, 2005.
48. Gierszewska, G.; Romanowska, M. *Analiza Strategiczna Przedsiębiorstwa*; PWE: Warsaw, Poland, 2003.
49. Obłój, K. *Strategia Organizacji. W Poszukiwaniu Trwałej Przewagi Konkurencyjnej*; PWE: Warsaw, Poland, 2007.
50. Krupski, R.; Stańczyk-Hugiet, E.; Niemczyk, J. *Koncepcje Strategii Organizacji*; PWN: Warsaw, Poland, 2009.
51. Zakrzewska-Bielawska, A. Ewolucja szkół strategii: Przegląd głównych podejść i koncepcji. *Pr. Nauk. Wałbrzyskiej Wyższej Szkoły Zarządzania Przedsiębiorczości* **2014**, *27*, 9–29.
52. Mohanty, K.; Dash, M. Approaches to strategy—A taxonomic study. *Int. J. Appl. Bus. Econ. Res.* **2017**, *15*, 619–630.
53. Niemczyk, J.; Trzaska, R. Analiza strategiczna przedsiębiorstwa w układzie podejść do strategii. *Przegląd Organ.* **2020**, *12*, 4–12. [CrossRef]
54. Martinet, C. Strategic planning, strategic management, strategic foresight: The seminal work of H. Igor Ansoff. *Technol. Forecast. Soc. Chang.* **2010**, *77*, 1485–1487. [CrossRef]
55. Ansoff, H.I. *Corporate Strategy. An Analytic Approach to Business Policy for Growth and Expansion*; McGraw Hill Book: New York, NY, USA, 1965.
56. Vancil, R.F.; Lorange, P. Strategic Planning in Diversified Companies. *Harvard Business Review*, January 1976.
57. Obłój, K. Strategia organizacji. In *Zarządzanie. Tradycja i Nowoczesność*; Bogdanienko, J., Piotrowski, W., Eds.; PWE: Warsaw, Poland, 2013; pp. 105–116.
58. McKiernan, P. Strategy futures. *Long Range Plan.* **1997**, *30*, 790–798. [CrossRef]
59. Romanowska, M. *Planowanie Strategiczne w Przedsiębiorstwie*; PWE: Warsaw, Poland, 2009.
60. Krawiec, F. *Strategiczne Myślenie w Firmie*; Difin: Warsaw, Poland, 2003.
61. Taylor, B. The return of strategic planning—Once more with feeling. *Long Range Plan.* **1997**, *30*, 334–344. [CrossRef]
62. Porter, M.E. What is strategy? *Harv. Bus. Rev.* **1996**, *74*, 61–78.
63. Porter, M.E. *Competitive Strategy: Techniques for Analyzing Industries and Competitors*; The Free Press: New York, NY, USA, 1990.
64. Chandler, A. *Strategy and Structure: Chapters in the History of the American Industrial Enterprise*; The MIT Press: Cambridge, MA, USA, 1969.
65. Wernerfelt, B. A Resource-Based View of the Firm. *Strateg. Manag. J.* **1984**, *5*, 171–180. [CrossRef]
66. Selznick, P. *Leadership in Administration: A Sociological Interpretation*; University of California Press: Berkley, CA, USA, 1984.
67. Selznick, P. *TVA and the Grass Roots: A Study in the Sociology of Formal Organization*; University of California Press: Berkeley, CA, USA, 1949.
68. Prahalad, K.; Hamel, G. *The Core Competence of the Corporation*; Harvard Business Review: Brighton, MA, USA, 1997; pp. 969–987.
69. Łobejko, S.; Pierścionek, Z. *Zarządzanie Strategiczne w Praktyce Polskich Przedsiębiorstw*; Oficyna Wydawnicza Szkoły Głównej Handlowej w Warszawie: Warsaw, Poland, 2011.
70. Stalk, G.; Evans, P.; Shulman, L.E. Competing on capabilities: The new rules of corporate strategy. *Harv. Bus. Rev.* **1992**, *70*, 57–69.

71. Amit, R.; Schoemaker, P.J.H. Strategic assets and organizational rent. *Strat. Manag. J.* **1993**, *14*, 33–46. [CrossRef]
72. Teece, J.; Pisano, G.; Shuen, A. Dynamic capabilities and strategic management. *Strateg. Manag. J.* **1997**, *18*, 509–533. [CrossRef]
73. Kay, J. *Podstawy Sukcesu Firmy*; Polskie Wydawnictwo Ekonomiczne: Warsaw, Poland, 1996.
74. Bower, J.L.; Christensen, C.M. Disruptive technologies: Catching the wave. *Harv. Bus. Rev.* **1995**, *73*, 43–53.
75. Manyika, J.; Chui, M.; Bughin, J.; Dobbs, R.; Bisson, P.; Marrs, A. Disruptive Technologies: Advanced that Will Transform Life, Business, and the Global Economy. 2013. Available online: https://www.mckinsey.com/~{}/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/disruptive%20technologies/mgi_disruptive_technologies_full_report_may2013.as (accessed on 5 December 2021).
76. Koutroumpis, P.; Lafond, F. *Disruptive Technologies and Regional Innovation Policy*; OECD: Paris, France, 2018. Available online: https://www.oecd.org/cfe/regionaldevelopment/KoutroumpisLafond(2018)Disruptive%20technologies%20and%20regional%20innovation%20policy_FI.pdf (accessed on 5 December 2021).
77. Chesbrough, H. Open innovation: Where we've been and where we're going. *Res. Technol. Manag.* **2015**, *55*, 20–27. [CrossRef]
78. West, J.; Salter, A.; Vanhaverbeke, W.; Chesbrough, H. Open innovation: The next decade. *Res. Policy* **2014**, *43*, 805–811. [CrossRef]
79. Rai, R.K. A co-opetition-based approach to value creation in interfirm alliances: Construction of a measure and examination of its psychometric properties. *J. Manag.* **2016**, *42*, 1663–1699. [CrossRef]
80. Kumar, A.; Connell, J.; Bhattacharyya, A. Co-opetition, corporate responsibility and sustainability: Why multi-dimensional constructs matter. *Soc. Responsib. J.* **2021**. ahead-of-print. [CrossRef]
81. Crick, J.M.; Crick, D. Coopetition and COVID-19: Collaborative business-to-business marketing strategies in a pandemic crisis. *Ind. Mark. Manag.* **2020**, *88*, 206–213. [CrossRef]
82. Kim, W.C.; Mauborgne, R. *Strategia Błękitnego Oceanu. Jak Stworzyć Wolną Przestrzeń Rynkową i Sprawić, by Konkurencja Stała się Nieistotna*; MT Biznes: Warsaw, Poland, 2005.
83. Gulati, R. Alliances and networks. *Strateg. Manag. J.* **1998**, *19*, 293–317. [CrossRef]
84. Thorelli, H.B. Networks: Between markets and hierarchies. *Strat. Manag. J.* **1986**, *7*, 37–51. [CrossRef]
85. Sus, A.; Organa, M.; Sulich, A. Effectiveness of relations in the inter-organizational oncological network in Poland—Research assumptions. *Transform. Bus. Econ.* **2019**, *18*, 745–766.
86. Ratajczak-Mrozek, M. Sieci Biznesowe a Przewaga Konkurencyjna Przedsiębiorstw Zaawansowanych Technologii na Rynkach Zagranicznych. Value Creation and Appropriation in Network Relationships of Digitized Companies View Project Global and Local Dimension of Business Networks View Project. Available online: https://www.researchgate.net/publication/282605866 (accessed on 15 September 2021).
87. McKiernan, P. *Strategies of Growth: Maturity, Recovery and Internationalization*; Routledge: London, UK; New York, NY, USA, 1992.
88. Cap, J.-P.; Blaich, E.; Kohl, H.; von Raesfeld, A.; Harms, R.; Will, M. Multi level network management—A method for managing inter-organizational innovation networks. *J. Eng. Technol. Manag.* **2019**, *51*, 21–32. [CrossRef]
89. Czakon, W. Sieci międzyorganizacyjne w naukach o zarządzaniu—W kierunku sieciowych modeli biznesu. *Zesz. Nauk. Uniw. Ekon. Katowicach* **2015**, *217*, 9–18.
90. Hovik, S.; Hanssen, G.S. The impact of network management and complexity on multi-level coordination. *Public Adm.* **2015**, *93*, 506–523. [CrossRef]
91. Niemczyk, J. Ewolucja strategii KGHM Polska Miedź SA a ewolucja podejść do strategii. *Res. Pap.* **2020**, *64*, 29–50. [CrossRef]
92. Jasiński, M. Identyfikacja Podejść do Strategii w Przedsiębiorstwach w Sektorze Produktów Spożywczych FMCG. UJĘCIE Metodyczne, Wroclaw University of Economics and Business, Wrocław, Poland, 2020. Unpublished work.
93. Di Clemente, R.; Chiarotti, G.L.; Cristelli, M.; Tacchella, A.; Pietronero, L. Diversification versus specialization in complex ecosystems. *PLoS ONE* **2014**, *9*, e112525. [CrossRef] [PubMed]
94. Niemczyk, J.; Jurczyk, J. Strategie wyższych uczelni w Polsce. Perspektywa podejść do strategii. *Pr. Nauk. Wałbrzyskiej Wyższej Szkoły Zarządzania Przedsiębiorczości* **2020**, *49*, 193–216.
95. International Institute for Management Development (IMD), World Competitiveness Ranking. 2021. Available online: https://www.imd.org/centers/world-competitiveness-center/rankings/world-competitiveness/#accordion-item-body-f9939679-cfc6-43fa-99d5-2babebe7b146 (accessed on 10 November 2021).
96. Data Browser, Share of Fossil Fuels in Gross Available Energy. 2021. Available online: https://ec.europa.eu/eurostat/databrowser/view/NRG_IND_FFGAE__custom_508218/bookmark/table?lang=en&bookmarkId=bac6396e-f558-4183-8180-b28193a17a32 (accessed on 3 December 2021).
97. Data Browser, Complete Energy Balances. 2021. Available online: https://ec.europa.eu/eurostat/databrowser/view/NRG_BAL_C__custom_1689348/default/table?lang=en (accessed on 3 December 2021).
98. TCdata360, GCI 4.0: Energy Efficiency Regulation. 2019. Available online: https://tcdata360.worldbank.org/indicators/hac1954b8?country=DEU&indicator=43074&countries=GBR,FRA,ITA,ESP,POL,ROU,NLD,BEL,GRC,CZE&viz=bar_chart&years=2019 (accessed on 3 December 2021).
99. TCdata360, GCI 4.0: Renewable Energy Regulation. 2019. Available online: https://tcdata360.worldbank.org/indicators/hedcd1e68?country=DEU&indicator=43077&countries=FRA,POL,BEL,CZE,GRC,ITA,NLD,ROU,ESP,GBR&viz=bar_chart&years=2019 (accessed on 3 December 2021).
100. World Economic Forum. *Committed to Improving the State of the World. Annual Report*; World Economic Forum: Cologny, Switzerland, 2020.

101. World Economic Forum. Fostering Effective Energy Transition 2020 Edition. 2020. Available online: https://www3.weforum.org/docs/WEF_Fostering_Effective_Energy_Transition_2020_Edition.pdf (accessed on 3 December 2021).
102. Zakrzewska-Bielawska, A. Ewolucja szkół strategii: Przegląd głównych podejść i koncepcji. In *Zarządzanie Strategiczne. Rozwój Koncepcji i Metod*; Krupski, R., Ed.; Prace Naukowe Wałbrzyskiej Wyższej Szkoły Zarządzania i Przedsiębiorczości: Wałbrzych, Poland, 2014; pp. 9–29.
103. Garcia, R.; Lessard, D.; Singh, A. Strategic partnering in oil and gas: A capabilities perspective. *Energy Strat. Rev.* **2014**, *3*, 21–29. [CrossRef]
104. Teng, T.; Cao, X.; Chen, H. The dynamics of inter-firm innovation networks: The case of the photovoltaic industry in China. *Energy Strat. Rev.* **2021**, *33*, 100593. [CrossRef]
105. Ziółkowska, B. Sieciowe uwarunkowania kształtowania strategii wzrostu wartości przedsiębiorstwa. *Ann. Univ. Mariae Curie Skłodowska Sectio H Oeconomia* **2016**, *49*, 751–759. [CrossRef]
106. Transform Your Text into Word Clouds! Available online: https://worditout.com/ (accessed on 10 November 2021).

energies

Article

From Words to Deeds: The Impact of Pro-Environmental Self-Identity on Green Energy Purchase Intention

Magdalena Grębosz-Krawczyk [1], Agnieszka Zakrzewska-Bielawska [2,*] and Sylwia Flaszewska [2]

1 Department of European Integration and International Marketing, Faculty of Management and Production Engineering, Lodz University of Technology, 90-924 Lodz, Poland; magdalena.grebosz@p.lodz.pl
2 Department of Management, Faculty of Management and Production Engineering, Lodz University of Technology, 90-924 Lodz, Poland; sylwia.flaszewska@p.lodz.pl
* Correspondence: agnieszka.zakrzewska-bielawska@p.lodz.pl

Abstract: This study examines the mechanism by which pro-environmental self-identity (PESI) affects green energy purchase intention (GEPI) through different dimensions of consumption values. The concept of pro-environmental self-identity is rarely discussed in the context of green energy purchase intention. Additionally, the amount of research concerning consumers' attitudes and behaviours towards photovoltaic panels is limited. We fill this cognitive gap by testing a relation between pro-environmental self-identity and green energy purchase intention. The data collection was carried out based on an indirect method of gathering information—using an online survey. Research was conducted among 250 Polish customers. The partial least squares structural equation modelling technique was applied. The research results show that the relations between PESI and GEPI is mediated totally by social and partially by emotional values. The mediating impact of functional values was not confirmed. The results of this study illustrate the importance of intangible—social and emotional—values and its impact on the consumer behaviour toward green energy. This study can help marketers more efficiently promote the installation of photovoltaic panels in European countries.

Keywords: pro-environmental self-identity; green energy purchase intention; photovoltaic panels; social value; emotional value

Citation: Grębosz-Krawczyk, M.; Zakrzewska-Bielawska, A.; Flaszewska, S. From Words to Deeds: The Impact of Pro-Environmental Self-Identity on Green Energy Purchase Intention. *Energies* **2021**, *14*, 5732. https://doi.org/10.3390/en14185732

Academic Editors: Bernard Ziębicki and Edyta Bielińska-Dusza

Received: 18 August 2021
Accepted: 8 September 2021
Published: 11 September 2021

1. Introduction

The development of the modern world, which has been driven mainly by the desire to improve people's quality of life, has been accompanied by an important increase in energy demand. In the second half of the XXth century, the international community started thinking about the increase in global energy consumption and its long-term consequences such as pollution of the atmosphere, soil and water. Nowadays, the eyes of the whole world are turned toward climate change. On the one hand, we need to increase energy production, but at the same time, it is necessary to protect the natural environment. Most countries in the world allocate important resources to encourage the use of renewable energy sources to protect natural resources and reduce pollution.

In 2020, the renewable energy use in the world increased 3% while the demand for all other fuels decreased. It was caused by an almost 7% growth in electricity generation from renewable sources. Consequently, the share of renewables in worldwide electricity generation increased to 29% in 2020 (in comparison with 27% in 2019) [1]. Thanks to policy support, the market of photovoltaic panels has developed in China, the United States, India, Brazil and Vietnam. In total, electricity generated from photovoltaic panels is estimated to grow by 145 TWh (18%), and will achieve about 1000 TWh by 2021 [1].

Previous research concerning green energy has concentrated especially on consumers' environmental concerns, attitudes, awareness, knowledge or responsibility [2–19], as well as internal and external factors influencing customers' intentions to adopt green energy [20–24].

The area of research concerning factors influencing consumer decisions in case of photovoltaic panels is still evolving in the scientific literature. We consequently observe important progress in the practical and theoretical aspects of this research [7,18,25–32]. Nonetheless, the international literature lacks a defined picture of the issues of pro-environmental self-identity that consumers of green energy are experiencing. Such information would provide both theoretical and managerial implications. Pro-environmental self-identity (PESI) has not been considered alongside consumption values and green energy purchase intention (GEPI) in the research regarding photovoltaic panel adoption. Consequently, we identified a research gap and confirmed the novelty of the problem. Previous papers concerning green energy adoption in Poland concentrated on the factors determining adoption by testing the willingness of customers to pay for green energy, to convert to green energy tariffs, and to install small-scale generators [29,33]. Therefore, the interconnection between the issue of pro-environmental self-identity and consumers' green energy purchase intention seems to be an innovation that this study brings compared with others that approached the same topic of study [7,18,25–32].

The objective of this paper is to evaluate the impact of pro-environmental self-identity on consumers' green energy purchase intention through different dimensions of chosen consumption values. The scientific problem was expressed through the following research question: How do functional, social and emotional values affect the relations between pro-environmental self-identity and consumers' green energy purchase intention?

This article can contribute to a better understanding of the importance of various factors influencing green energy purchase intention. The topic is important, taking into account the increasing use of photovoltaic panels and growing ecological attitudes of modern consumers. In their studies, Van Der Werff et al. [34], Barbarossa and de Pelsmacker [35] and Mutum et al. [36] highlighted the impact of self-identity on purchase intention of green products, but these issues were not discussed in the context of green energy adoption. Our contribution lies in using pro-environmental self-identity to explain sustainable energy adoption. We would like to strengthen this contribution by appraising the mediating effect of chosen consumption values between pro-environmental self-identity and green energy purchase intention.

The paper consists of five sections. The first is an introduction. The theoretical framework with characteristics of the European photovoltaic sector, the literature review concerning pro-environmental self-identity and its relation with consumption values and green energy purchase intention, and the hypotheses of the study are presented in Section 2. In Section 3, the research methodology is described. The results are presented in Section 4. To finish, in Section 5, the discussion and conclusions with managerial and theoretical contributions, as well as the limitations of this study, are formulated.

2. Theoretical Framework

2.1. The Characteristics of the European Photovoltaic Sector

In the past ten years, the EU has continued a proactive climate policy and incorporated a considerable amount of renewables into the energy system [37]. Therefore, renewable energy is one of the important areas of EU policy [38]. Renewable energy is a source of economic growth and jobs for Europeans. The larger amounts of renewable energy are a significant factor behind the decline in wholesale energy prices in previous years. It can in turn decrease energy costs for industry and possibly improve industrial competitiveness. Finally, the dropping costs of the technology, combined with digitalisation, is making renewables an important driving force for permitting consumers to play a central role in the energy transition [39].

EU countries, every second year, inform on their progress towards the EU's 2020 renewable energy goals. Based on the national statements, the European Commission creates an EU-wide report that gives an overview of renewable energy policy developments in EU countries. Available data show that the EU is on the right track for reaching its renewable energy goals for 2020. In 2018, twelve Member States already achieved a renewable energy share above their respective 2020 targets. Eleven other Member States met or exceeded their RED I average indicative trajectory for 2017–2018. Five Member States (France, Ireland, the Netherlands, Poland and Slovenia) failed to do so [39]. Ambitions of renewable energy targets are consistently raised in many countries [40].

One of the fastest growing renewable sources of electricity is solar energy. One of the most promising technologies all over the world is solar photovoltaic panels [41]. In 2020, 134 TWh of solar energy was produced in the EU-28 countries, mostly in Germany (49 TWh), Spain (15 TWh) and France (13 TWh). Poland's result was at the level of 1.9 TWh. This accounts for around 1.5% of the total electricity produced in Poland in 2020, which is seven times more than in 2018. This is mainly the result of the popularization of photovoltaic panels installed by prosumers and government forms of support, such as My Electricity program implemented from September 2019 to December 2020. It is estimated that in 2021 Poland will obtain as much as 3.5% of its electricity from solar energy [42,43].

Referring to the increase in installed power in photovoltaics, it was about 153 GW in the European Union countries. Germany did best with an increase of 4.74 GW, followed by the Netherlands (3 GW) and Spain (2.8 GW). Poland, with a result of 2.4 GW, was placed fourth. Detailed data on Poland prove that 2020 was the best year in the history of photovoltaic development. The installed power in photovoltaics was 3.936 MW at the end of 2020, which means growth of 2.463 MW year on year, translating to a 200% annual rise. Individual prosumers made the largest input to the increase in new power [43]. Importantly, despite the difficult period caused by the global pandemic, domestic photovoltaic made a significant contribution to the maintenance of investment processes to the tune of PLN 9.5 billion and provided Poland with 35 thousand jobs [43]. The growing ecological awareness of Polish people and the financial benefits associated with investing in a home photovoltaic installation translate into a large increase in interest in such a solution. Photovoltaic panels have proven themselves both as a technology that allows for a significant reduction in electricity bills and as an environmentally friendly solution [42,43].

The dynamics of the development of the photovoltaic market remains high in the EU-28 countries. Poland is the leader of Europe under the growth rate of photovoltaic power, calculated based on the compound annual growth rate (CAGR). Sweden, Hungary, Ukraine, the Netherlands and Spain are behind Poland [43].

2.2. Consumers' Pro-Environmental Self-Identity (PESI) and Its Relation with Consumption Values and Green Energy Purchase Intention

Pro-environmental self-identity (PESI)—also called green self-identity—is described as the consumers' self-obligation to protect the environment through their everyday behaviour [34,44]. Self-identity is a main predictor of consumption choice-making [45]. Consequently, it is significant also in explaining pro-environmental behaviour. In the opinion of Sparks and Shepherd [46], self-identity influence is stronger than attitudes and values. According to Dermody et al. [47] pro-environmental self-identity is an "environmentally friendly self-concept that is symbolically expressive and shaped by mainstream socio-cultural forces". Accordingly, pro-environmental self-identity is situationally cued. In consequence, these cues direct consumers' ecological behaviours [47–51].

Consumers with PESI tend to consider green behaviour an obligation that has a significant influence on the purchase intention of environmentally friendly products [52,53]. According to Van De Werff et al. [34], pro-environmental self-identity is related to consumers' obligation-based intrinsic motivation to behave pro-environmentally, and consequently it affects pro-ecological actions.

By practising green behaviours, consumers can feel better and perceive that their activities affect positively on environmental protection [36]. Bei and Simpson [54] stated that respondents perceived purchasing recycled products as an act of ecological protection and Wüstenhagen and Bilharz [16] found that the motivation for buying green electricity at a premium is to feel better about themselves.

Dermody et al. [47] confirmed that PESI has a significant influence on Polish and Chinese consumers' buying and curtailment behaviours. Thorbjørnsen et al. [55], Whitmarsh and O'Neill [50] and Mutum et al. [36] found that green consumption behaviours are correlated with PESI.

According to the theory of reasoned action (TRA) model, developed by Ajzen and Fishbein [56] and the theory of planned behaviour model proposed by Ajzen [57], an individual's performance of a specific behaviour is determined by his/her behavioural intention to perform the behaviour. In the case of studies concerning environmentally friendly consumer behaviours, the purchase intention of green products is understood as a customer's intention to buy a product that is less dangerous for both the environment and society [58]. Oliver and Lee [59] defined the purchase intention of the green product as a customer's real purchase of an environmentally friendly product once the customer is conscious of its ecological features. In our research, green energy purchase intention (GEPI) is related to the consumer's actual purchase or the consumer's intention to buy an environmentally friendly installation of photovoltaic panels.

In this context, a question arises whether the relation between PESI and green energy purchase intention is determined by any other factors. Seeking the answer, we used the consumption values theory. This theory provides fundamental and comprehensive constructs representing different values including functional, social, emotional, epistemic, and conditional values that are independent [60,61]. The consumption values theory was analysed in the context of green consumer behaviours by several researchers [61,62]. From different consumption values, three were supposed to be crucial for mediating the relation between PSEI and green energy purchase intention, which are: functional, social, and emotional values.

Functional value can be described as the perceived utility through the possession of the main functional, physical, or utilitarian attributes [60,63–66]. The positive impact of product utilitarian and physical attributes on the intention to purchase green products has been confirmed in different studies [32–38,41]. Wang et al. [67] and Yao et al. [68] also underlined the role of price–quality relation in the product evaluation. Consumers often complain about the high prices of green products, and they perceive ecological products as expensive in comparison to conventional ones. Consequently, a high price may influence purchase decisions, especially when consumers are price sensitive [69]. Previous research has confirmed the relation between price and green purchase intention [69–72]. In the case of green energy, purchases can be driven by functional value that determines the installation choice [9,10]. On the other hand PESI can determine the functional value because consumers are able to accept the green offer if its features and functions bring a potential positive effect to the environment. According to Chen and Chang [73], a consumer's opinion concerning the benefit of a product is based on the consumers' green needs, desires or sustainable expectations. Additionally, the study of Confente et al. [44] showed that the perceived functional value of green product is driven by consumers' pro-environmental self-identity. Therefore, we came up with following hypothesis:

Hypothesis 1 (H1). *Functional value mediates the relation between pro-environmental self-identity and green energy purchase intention.*

Social value can be described as the perceived utility by the connotation with positively or negatively stereotyped demographic, cultural, social, economic, and ethnic groups [60,74]. According to the social identity theory (SIT), social membership gives an individual a sense of belonging [75]. The needs of belonging and acceptance by the group influences the choices of a consumer. Consequently, an individual defines himself through the prism of his group membership; that is, his place in the societal system. In this regard, social identity predefines an individual's attributes as a member of that group; that is, self-perception and conduct.

The adoption of solar PVs can be affected by social-interaction effects because social norms can encourage consumers to invest in pro-environmental activities [14,32,76–79]. Caird et al. [8], Kaenzig and Wüstenhagen [9], Salazar et al. [80], Lee [81] and Klepacka [11] confirmed a positive relation between social values and consumers' purchase behaviour toward environmentally friendly products. PESI is related with the way an individual sees himself and how he wants to follow the behaviours and values of the groups to which he wants to belong or belongs [36,47,50]. The conclusions from previously mentioned research suggest that the value system of a consumer can affect the value of green products and the degree to which the consumer identifies himself as a member of the green community. Therefore, we proposed a second hypothesis:

Hypothesis 2 (H2). *Social value mediates the relation between pro-environmental self-identity and green energy purchase intention.*

Emotional value can be defined as perceived utility related with a new product satisfying the consumer's sentimental needs and delivering novelty through the creation or perpetuation of feelings or affective states [60,63,64].

Yoo et al. [82], Lin and Huang [64], Rex and Baumann [83] and Hartmann et al. [84] found a positive relationship between consumers' purchasing decisions and emotional value. On the other hand, there is also a positive relationship between pro-environmental self-identity and emotional value, which was proved among others by Confente et al. [44] and Mutum et al. [36]. Consumers can accept photovoltaic panels if the fit between the consumers' personal values and PV's modern traits is also underlined. The emotional value of green products can be influenced by consumers' pro-environmental self-identity, particularly if the consumer can see a strong similarity between himself and the product. Therefore, we assumed another hypothesis:

Hypothesis 3 (H3). *Emotional value mediates the relation between pro-environmental self-identity and green energy purchase intention.*

3. Materials and Methods

3.1. Sample

To achieve the objective of this research and to verify the hypotheses, the survey was conducted in January 2021. The sampling frame consisted of 250 Polish consumers who were house owners or co-owners. We used a self-administered questionnaire and random selection [85]. These consumers were selected from a database prepared by Norstat, which has a lot of experience in market research and offers online panels of 650,000 consumers from eighteen European countries who are highly motivated, pre-profiled, and open to various digital research methods. For Poland, the active panel counts 41,752 consumers over 18 years old. The population of Poland in 2020 was about 38.6 million people [86] and Internet penetration was 78% [87].

In the first stage, a pilot test was conducted with ten randomly selected house owners. During the process, respondents checked the content and relevance of each item to make sure every question is adequate and accurately understood. Based on the feedback from pre-testing, minor modifications were made to the questionnaire.

In the second stage, the sample of 1000 consumers was randomly selected from a Norstat database of 12,329 consumers who are owners and co-owners of houses. Of this sample, 250 consumers (25%) responded to the questionnaire. Such a response rate is acceptable for this type of survey [88]. Of these respondents, 43.6% were female and 56.4% were male (Table 1). Almost half of the respondents were people with higher education aged between 35 and 54 years old with houses that are more than 30 years old, mainly in the countryside. However, the women were younger than the men, and the men were better educated.

Table 1. Demographic description of respondents.

Demographic Descriptors	General (%) 250 = 100%	Female (%) N = 109	Male (%) N = 141
Age			
<18–24>	8.4	5.6	2.8
<25–34>	19.2	10.0	9.2
<35–44>	23.6	14.8	8.8
<45–54>	24.0	7.6	16.4
<55–64>	14.8	3.6	11.2
65+	10.0	2.0	8.0
Education			
primary	11.6	4.0	7.6
secondary	41.2	22.4	18.8
higher	47.2	17.2	30.0
Place of residence			
countryside	45.6	20.8	24.8
city with population less than 50 thousand inhabitants	26.4	12.8	13.6
city with population from 50 up to 150 thousand inhabitants	10.8	4.8	6.0
city with population from 150 up to 500 thousand inhabitants	11.6	3.6	8.0
city with population bigger than 500 thousand inhabitants	5.6	1.6	4.0
Age of house			
less than 5 years	7.2	3.6	3.6
5–10 years	9.6	3.6	6.0
11–20 years	22.4	7.2	15.2
20–30 years	14.4	8.4	6.0
over 30 years	46.4	20.8	25.6

To reduce biases, the respondents were asked to fill in the questionnaire on different days and time slots [89]. We checked the response bias issue based on the procedure suggested by Armstrong and Overton [90]. We compared early and late respondents and key demographic variables, such as gender, age, education, and place of residence using t-tests. All t-statistics were insignificant, suggesting that response bias was unlikely to affect our findings [91].

3.2. Measures, Validation and Reliability Analysis

The questionnaire consisted of 22 items taken from the literature measuring basic constructs, such as pro-environmental self-identity, green energy purchase intention, functional, social, and emotional value, and the demographic characteristics of respondents (indicated in a Table 1), which played the role of control variables. This study used existing scales from the literature focusing on consumption value theory as well as green consumers' attitudes and behaviours. We used multi-item Likert scales (from 1—strongly disagree to 5—strongly agree) that are used in the literature for the purposes of constructing operationalization and allowing questioning without systematic errors [92]. A list of the scales used with associated items is presented in Appendix A.

Pro-environmental self-identity (PESI) was measured by means of four items adapted from Barbarossa and de Pelsmacker [35], Dermody et al. [48], and Whitmarsh and O'Neill [50] through which the respondents were asked to indicate their level of agreement or disagreement with presented statements concerning their attitudes and behaviours to protect the environment. An example of the items we used is "I am willing to commit myself to environmental protection" or "I am convinced that my personal responsibility for the problems of the environment is important".

Green energy purchase intention (GEPI) was also measured by four items adapted from Yoo and Donthu [93] and Chan [94]. These items, e.g., "I have installed/would install photovoltaic panels instead of using conventional energy sources due to worsening environmental conditions" or "I would install/have installed photovoltaic panels for ecological reasons", focus on the intention of the consumer to buy a product that is less dangerous for both the environment and society (in this case photovoltaic panels).

Consumption values, such as functional, social, and emotional value measures were served as mediators in the relation between PESI and GEPI.

Functional value (FV). Six items were used to measure functional value adopted from Sangroya and Nayak [4], Zailani et al. [65], and Sweeney and Soutar [62]. Some items described functional value in terms of economic utility and rationalism, such as "The photovoltaic panels are reasonably priced", and some consider product quality and attributes, such as "The photovoltaic panels available on the market are of good quality".

Social value (SV). This value is measured by five items proposed by Sweeney and Soutar [62], Zailani et al. [65], and Yoo et al. [82], who described it as the gain acquired from acceptability in different social groups [95]. As example item is "Photovoltaic panels installation improves the image of its owner" or "Photovoltaic panel installation gives its owner social approval".

Emotional value (EV). This study defined emotional value as the perceived utility acquired from a customer's feelings. It used research from Yoo et al. [82], Arvola et al. [96], and Khan and Mohsin [97] to measure emotional value with three items, such as "Installing photovoltaic panels as an alternative to conventional energy sources would make me feel like a better person".

We followed a procedure proposed by Gerbing and Anderson [98] and Hair et al. [99] to evaluate the unidimensionality, validity, and reliability of the constructs. Because all our items are adopted from literature, we used a confirmatory factor analysis (CFA) with maximum likelihood estimation [100] to assess the reliability and validity of the multi-item scales. Table 2 presents the results of CFA.

All factor loadings were higher than 0.7 and all t-tests of the observed variables were significant at the 0.001 level with *t*-values greater than 2. In addition, the average variance extracted (AVE) values were higher than 0.50. Consequently, we confirmed the convergent validity of the scales [101].

Discriminant validity helps to check the extent to which the constructs are statistically different from each other [101], suggesting that the square root of AVE of any construct should be higher than the inter-construct correlation. Table 3 shows that the square root of the AVE of the constructs exceeded the correlations of the constructs. There is one exception relating to the correlation between SV and EV. In this case, the correlation is higher than the square root of the AVE, which means that these variables should be considered in separate models instead of in one. Except for this limitation, discriminant validity was established.

Table 2. The confirmatory factor analysis results.

Variable/Items	Loading	*t*-Value	Convergent Validity	Reliability	
			AVE	Cronbach's α	CR
Pro-environmental self-identity (PESI)					
PESI 1	0.774	-	0.557	0.834	0.838
PESI 2	0.745	9.35			
PESI 3	0.703	8.83			
PESI 4	0.762	10.22			
Green energy purchase intention (GEPI)					
GEPI 1	0.828	-	0.506	0.797	0.800
GEPI 2	0.752	5.77			
GEPI 3	0.768	4.75			
GEPI 4	0.774	9.21			
Functional value (FV)					
FV 1	0.912	-	0.535	0.865	0.870
FV 2	0.864	13.35			
FV 3	0.695	9.16			
FV 4	0.605	8.18			
FV 5	0.643	9.43			
FV 6	0.675	9.59			
Social Value (SV)					
SV 1	0.787	-	0.563	0.865	0.866
SV 2	0.719	7.01			
SV 3	0.722	6.63			
SV 4	0.765	9.04			
SV 5	0.758	9.18			
Emotional value (EV)					
EV 1	0.721	-	0.601	0.811	0.817
EV 2	0.864	9.98			
EV 3	0.732	7.74			

Table 3. Descriptive statistics, discriminant validity and correlations between variables.

Variable	PESI	GEPI	FV	SV	EV
PESI	0.746				
GEPI	0.689 ***	0.712			
FV	0.602 ***	0.553 ***	0.731		
SV	0.721 ***	0.689 ***	0.668 ***	0.750	
EV	0.727 ***	0.690 ***	0.683 ***	0.824 ***	0.775
Mean	4.09	3.81	3.54	3.61	3.81
s.d.	0.75	0.82	0.68	0.78	0.84

Note. N = 250; s.d.—standard deviation; the diagonal values (in bold) present the square roots of AVE; correlation is statistically significant for $p < 0.01$ (***).

The reliability of scales was conducted by calculating composite reliability (CR) and Cronbach's α. Cronbach's alpha values for all the scales exceeded 0.7 and passed the recommended threshold level [99]. Similarly, the CR of all the constructs were above the threshold value of 0.7, suggesting internal consistency and reliability [101].

To verify the extent to which our data are likely to suffer from common method bias, we guaranteed the anonymity of respondents and confidentiality of the study, affirmed that there are no correct or incorrect responses, and that they should respond honestly [102]. We also took care with particular items to ensure that they were not ambiguous, vague, or unfamiliar, and we formulated the questionnaire as concisely as possible, pre-testing it in a pilot study.

In addition, we performed Harman's single factor test and we followed the approach of Podsakoff et al. [103] for controlling for an unmeasured latent factor. Common method variance is possible if items load on multiple factors and one factor does not account for most of the covariance. Our analysis, i.e., an unrotated principal component factor analysis, principal axis analysis with varimax rotation, and principal component analysis with varimax rotation revealed the presence offive5 distinct factors with an eigenvalue greater than 1.0, rather than a single factor. The cumulative variance was 72.4%. The first factor explains less than half of the overall variance (20.3%), implying that single-source bias is not a significant concern.

Summing up, the CFA supported our measurement model and showed that pro-environmental self-identity, green energy purchase intention, functional value, social value, and emotional value are five distinct constructs.

For our analysis, we employed two statistical packages, Statistica and Amos, which enabled us to enter data in numerical form and then carry out statistical analyses, facilitating and accelerating the process of developing research results. In addition, Amos was useful for the visualization of the structural equations.

4. Results

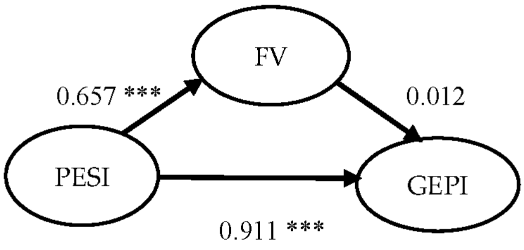
To test our hypotheses, first we verified that there was no basis to reject the Gauss–Markov assumptions following a procedure proposed by Hair et al. [99], then we performed structural equation modelling (SEM) with maximum likelihood (ML) estimation and covariance matrix as data inputs. This method is frequently selected to test and develop a theory [104]. Due to the mentioned limitation of discriminant validity (the correlation between SV and EV is higher than the square root of the AVE), we were not able to build one SEM model. Therefore, for our analyses, we built three separate SEM models to test the mediating impact of FV, SV, and EV on the relationship between PESI (independent variable) and GEPI (dependent variable). Firstly, we checked a direct effect, i.e., we tested whether the pro-environmental self-identity (PESI) affected green energy purchase intention (GEPI). Next, we examined the mediation (indirect) effect between independent (PESI) and dependent (GEPI) variables using particular mediators, such as FV, SV, and EV. For each model, we checked the following statistics: goodness of fit index (GFI), comparative fit index (CFI), root mean square error of approximation (RMSEA), Tucker–Lewis index (TLI), and adjusted goodness of fit index (AGFI). The results are presented in Figure 1 and Table 4.

Table 4. Results of structural equation modelling.

Path Analysis	Unstandar. Coefficients		Standar. Coefficients β	*t* Value	*p* Value	Results
	B	SE				
Model 1						
PESI → GEPI	1.152	0.121	0.911	9.553	0.000 ***	H1 is not confirmed
PESI → FV	0.646	0.069	0.657	9.349	0.000 ***	
FV → GEPI	0.016	0.096	0.012	0.165	0.869	
Model 2						
PESI → GEPI	0.400	0.248	0.321	1.611	0.107	H2 is confirmed
PESI → SV	0.860	0.084	0.927	10.265	0.000 ***	
SV → GEPI	0.868	0.273	0.644	3.179	0.001 ***	
Model 3						
PESI → GEPI	0.516	0.222	0.408	2.325	0.020 *	H3 is confirmed
PESI → EV	0.864	0.078	0.903	11.014	0.000 ***	
EV → GEPI	0.745	0.235	0.564	3.170	0.002 ***	

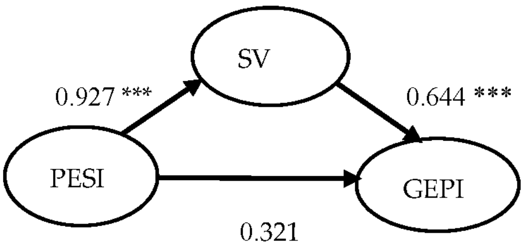
Note. N = 250; significance level for $p < 0.01$ (***); significance level for $p < 0.05$ (*); SE—standard error; *B*—unstandardized path coefficient.

(a) Functional value as mediator between PESI and GEPI



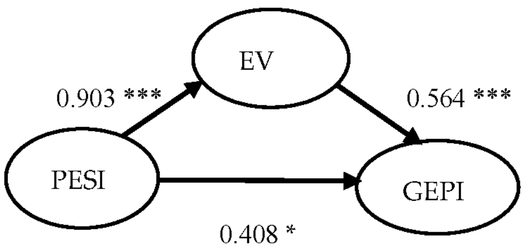
Evaluation of the SEM model		
$\chi2/df$		max. 2.00
RMSEA	0.091	max. 0.10
GFI	0.946	<0.90; 1.00>
CFI	0.976	<0.90; 1.00>
TLI	0.948	<0.90; 1.00>
AGFI	0.928	<0.90; 1.00>

(b) Social value as mediator between PESI and GEPI



Evaluation of the SEM model		
$\chi2/df$		max. 2.00
RMSEA	0.086	max. 0.10
GFI	0.908	<0.90; 1.00>
CFI	0.963	<0.90; 1.00>
TLI	0.928	<0.90; 1.00>
AGFI	0.905	<0.90; 1.00>

(c) Emotional value as mediator between PESI and GEPI



Evaluation of the SEM model		
$\chi2/df$		max. 2.00
RMSEA	0.089	max. 0.10
GFI	0.998	<0.90; 1.00>
CFI	0.917	<0.90; 1.00>
TLI	0.965	<0.90; 1.00>
AGFI	0.937	<0.90; 1.00>

Figure 1. SEM models of direct and indirect (mediation) effect; Note. N = 250; significance level for $p < 0.01$ (***); significance level for $p < 0.05$ (*).

Hypothesis H1, considering the mediation effect of the functional value (FV) on the relation between the pro-environmental self-identity (PESI) and green energy purchase intention (GEPI) must be rejected. There is no significant impact of FV on GEPI (β = 0.012; $p > 0.05$), therefore no mediation effect exists.

Social value (SV) is significantly associated with PESI (β = 0.927; $p < 0.01$) and with GEPI (β = 0.644; $p < 0.01$), which supports Hypothesis H2. There is no significant impact of PESI on GEPI, which confirms total mediation effect. It means that the pro-environmental self-identity impacts consumers' green energy purchase intention but only through the social value, i.e., the perceived utility through the connotation with one or more social, economic, cultural, or demographic groups.

Emotional value (EV) partially mediates the relationship between PESI and GEPI. PESI is significantly associated with GEPI (β = 0.408; $p < 0.05$) but also with EV (β = 0.903; $p < 0.01$), and EV is significantly associated with GEPI (β = 0.564; $p < 0.01$). It means that PESI affects GEPI directly and indirectly through EV which expresses a partial mediation effect and confirms Hypothesis H3.

Considering the control variables (respondents' gender, level of education, place of residence, and age of the house), some differences appeared. We grouped our respondents into two bigger subgroups (with minimum n = 60) within a single control variable as follows: males (n = 141) and females (n = 109); younger people (18–44 years old; n = 128) and older people (over 44 years old; n = 122); people with higher education (n = 118) and people with primary or secondary education (n = 132); people living in the countryside (n = 114) and people living in cities (n = 136); people who are owners of a house built less than 30 years ago (n = 134) and those who own a house built over 30 years ago (n = 116). The mediation effect of social value on the relation between pro-environmental self-identity and consumers' green energy purchase intention is:

- stronger for older people, i.e., people 45+ years old (β = 0.930; $p < 0.01$ for PESI → SV path dependence and β = 0.949; $p < 0.01$ for SV → GEPI path dependence),
- stronger for people with higher education (β = 0.936; $p < 0.01$ for PSEI → SV path dependence and β = 0.943; $p < 0.01$ for SV → GEPI path dependence),
- weaker for people from cities (β = 0.893; $p < 0.01$ for PESI → SV path dependence and β = 0.631; $p < 0.01$ for SV → GEPI path dependence),and
- weaker for owners who have had the house for a long time (β = 0.867; $p < 0.01$ for PESI → SV path dependence and β = 0.505; $p < 0.01$ for SV → GEPI path dependence)

In the case of the mediation effect of emotional value on the relation between pro-environmental self-identity and consumers' purchase intention of photovoltaic panel installations, the following differences were identified:

- for people over 44 years old, the emotional value totally and strong mediates the relation between PESI and GEPI (β = 0.928; $p < 0.01$ for PESI → EV path dependence and β = 0.607; $p < 0.01$ for EV → GEPI path dependence) as well as for owners who have had the house for over 30 years (β = 0.974; $p < 0.01$ for PESI → EV path dependence and β = 0.715; $p < 0.01$ for EV → GEPI path dependence),
- for people from cities, the emotional value totally but not as strongly mediates the relation between PSEI and GEPI (β = 0.848; $p < 0.01$ for PESI → EV path dependence and β = 0.; $p < 0.01$ for EV → GEPI path dependence).

In both cases of mediation effects, i.e., impact of social and emotional values on the relation between PESI and GEPI, there were no statistically significant differences in terms of gender.

5. Discussion and Conclusions

The research results affirm the results of previous studies by Van Der Werff et al. [34], Barbarossa and de Pelsmacker [35] and Mutum et al. [36], who highlighted self-identity as an antecedent of purchase intention for green products. Our study focuses on consumers' intentional decision-making regarding photovoltaic panels in the context of pro-environmental self-identity and theory of consumption values, thus developing the discussion on crucial factors influencing green energy purchase intention, which contributes to sustainable development and it thus desirable in today's world.

Research results showed that the relationship between pro-environmental self-identity (PESI) and green energy purchase intention (GEPI) is mediated by social, and partially emotional, values. Other studies also confirmed that PESI mediates the relationship between values and consumer behaviour [34,50]. As Confente et al. [44] mentioned, pro-environmental self-identity is an important component of an individual's value-construction process.

The importance of social value was confirmed by Mutum et al. [36], who stated that social value mediated the relationship between PESI and green purchase behaviour (GPB). The research results also confirmed those of previous studies suggesting that social influence and environment respect affect consumers' green purchase behaviours [54,60,105]. PESI supports the positive associations of photovoltaic panels with eco-friendly communities and consequently in this context supports consumers' purchase behaviours. Consumers' personal self-obligation to protect the environment is reinforced by a need for social acceptance, which affects purchase intention. The relation between personal moral norms reinforced by public approval and intention of green purchase was also underlined by Chowdhury et al. [52] and Attaran and Celik [53]. External, expert opinions are important, especially for older people without experience with modern energy solutions who feel responsible for the environment.

Our research results also show that emotional value partially mediates the relation between pro-environmental self-identity and green energy purchase intention. This was consistent with the findings of Yoo et al. [82], Lin and Huang [64], Rex and Baumann [83] and Hartmann et al. [84] concerning a positive relationship between emotional value and purchasing decisions, as well as with the studies of Confente et al. [44] and Mutum et al. [36] regarding the mediating effect of values. The importance of the emotional value of green products is observed especially in the case of the most engaged consumers that expect to change something like in the case of older people having a house for a long time. Eco-friendly behaviours related to the installation of photovoltaic panels are driven by consumers' feelings of being green energy creators. The same was proved by Sparks and Shepherd [46] for consumers' intention to buy eco-friendly products, which were affected by individuals' perceptions of being eco, as well as by Mannetti et al. [106], who found that recycling behaviours are driven by consumers' feelings of being recyclers.

The research results did not find support for the mediation effect of functional value. Similar conclusions were formulated by Mutum et al. [36], who studied the relationship between PESI and green purchase behaviour (GPB). This was consistent also with the results of Ecker at al. [107] who stated that consumers chose green energy source especially for independence, autonomy, self-sufficiency, supply security, and control, and not functional value. However, the opposite conclusions were formulated by Confente et al. [44] for bioplastic products.

From a theoretical standpoint, the research results contribute to the pro-environmental self-identity concept and its relation with consumption value theory as well as providing a better understanding of consumers' purchase intentions towards photovoltaic panel installation and consequently the development possibilities in the green energy sector in Europe, a sector that is under-researched. This paper can be a starting point for a scientific discussion, but also can be used by managers working in the sector of green energy.

Considering managerial implications, this study's results can be useful for marketers, ecological organisations, policymakers, and public institutions in developing their policies, strategies, and marketing communication campaigns to encourage photovoltaic panel installation. The approach to understand consumers' green behaviours based on emotional and symbolic values has significant implications. Representatives of public institutions should understand that for citizens, social values are more important than functional benefits, and thus offer legal solutions that will allow the development of green local communities. Such communities can jointly support the development of green energy. The results of this study can have consequences for companies from the green energy sector. They can be used during the creation of marketing communication strategies, especially during the selection of communication tools and the formulation of advertising messages, taking into account the differences between groups of consumers. The most relevant social and emotional values should be communicated by different communication channels used by photovoltaic panel producers. The results prove that social value importantly mediates the relationship between PESI and GEPI. Consequently, marketers should present the opinions of experts and influencers to affect consumer behaviour by increasing trust in green energy and minimizing the perceived risks of photovoltaic panel installation. They can also refer to consumers' sense of social responsibility. Taking into account that emotional value was also found to partially mediate the relationship between PESI and GEPI, marketing communication campaigns of public institutions and ecological organisations should include emotional appeals to encourage consumers to adopt green energy and appealing to their sense of responsibility for the environment by showing the negative effects of the long-term use of conventional energy.

These conclusions were formulated taking into account the sample's limitations. The study was limited to Polish consumers, the sample was relatively small, and we examined consumers' green energy purchase behaviour limited only to one source of green energy, i.e., photovoltaic panels. Therefore, this research can encourage further reflection on the impact of PESI and consumption values on green energy purchase intention. It seems interesting to undertake international studies enabling comparison between the attitudes of Polish consumers with consumers from other countries or expanding them to other sources of green energy and environmental knowledge as a mediator representing other consumer characteristics.

Author Contributions: General concept, M.G.-K. and A.Z.-B.; theory, M.G.-K. and S.F.; methodology, M.G.-K. and A.Z.-B.; validation and formal analysis, A.Z.-B.; investigation, M.G.-K.; data curation, A.Z.-B.; preparation of the draft version, M.G.-K., A.Z.-B. and S.F.; preparation of the draft version, M.G.-K., A.Z.-B. and S.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Key Constructs and Items

Pro-Environmental Self-Identity (PESI) [35,48,50]:

- (PESI 1) By buying photovoltaic panels, I help reduce environmental pollution.
- (PESI 2) I am willing to commit myself to environmental protection.
- (PESI 3) I am convinced that my personal responsibility for the problems of the environment is important.
- (PESI 4) I am convinced that my moral obligation to help the environment is important.

Green Energy Purchase Intention (GEPI) [94,95]:

- (GEPI 1) I installed/would install photovoltaic panels instead of using conventional energy sources due to worsening environmental conditions.
- (GEPI 2) I installed/would install photovoltaic panels instead of using conventional energy sources when there are discounts or other promotional activities.
- (GEPI 3) I installed/would install photovoltaic panels instead of using conventional energy sources when there are external subsidies available.
- (GEPI 4) I would install/installed photovoltaic panels for ecological reasons.

Functional Value (FV) [4,63,66]:

- (FV 1) The photovoltaic panels available on the market are of good quality.
- (FV 2) The photovoltaic panels available on the market are well made.
- (FV 3) Photovoltaic panels perform consistently.
- (FV 4) Photovoltaic panels are reasonably priced.
- (FV 5) Using photovoltaic panels offers value for money.
- (FV 6) Using photovoltaic panels offers future savings.

Social Value (SV) [63,66,83]:

- (SV 1) Photovoltaic panel installation improves the image of its owner.
- (SV 2) Photovoltaic panel installation makes a good impression on other people.
- (SV 3) Photovoltaic panel installation gives its owner social approval.
- (SV 4) Photovoltaic panel installation reflects environmental awareness.
- (SV 5) Photovoltaic panel installation reflects concern for the environment.

Emotional Value (EV) [83,97,98]:

- (EV 1) Photovoltaic panel installation as an alternative to conventional energy sources seems to me to be a personal contribution to the common good.
- (EV 2) Photovoltaic panel installation as an alternative to conventional energy sources is morally right for me.
- (EV 3) Photovoltaic panel installation as an alternative of conventional energy sources would make me feel like a better person.

References

1. *International Energy Agency (IEA) Global Energy Review 2021*; International Energy Agency: Paris, France, 2021.
2. Bronfman, N.C.; Jiménez, R.B.; Arévalo, P.C.; Cifuentes, L.A. Understanding social acceptance of electricity generation sources. *Energy Policy* **2012**, *46*, 246–252. [CrossRef]
3. Hartmann, P.; Apaolaza-Ibáñez, V. Consumer attitude and purchase intention toward green energy brands: The roles of psychological benefits and environmental concern. *J. Bus. Res.* **2012**, *65*, 1254–1263. [CrossRef]
4. Sangroya, D.; Nayak, J.K. Factors influencing buying behaviour of green energy consumer. *J. Clean. Prod.* **2017**, *151*, 393–405. [CrossRef]
5. Niemeyer, S. Consumer voices: Adoption of residential energy-efficient practices. *Int. J. Consum. Stud.* **2010**, *34*, 140–145. [CrossRef]
6. Tsoutsos, T.; Drandaki, M.; Frantzeskaki, N.; Iosifidis, E.; Kiosses, I. Sustainable energy planning by using multi-criteria analysis application in the island of Crete. *Energy Policy* **2009**, *37*, 1587–1600. [CrossRef]
7. Sovacool, B.K.; Lakshmi Ratan, P. Conceptualizing the acceptance of wind and solar electricity. *Renew. Sustain. Energy Rev.* **2012**, *16*, 5268–5279. [CrossRef]
8. Caird, S.; Roy, R.; Herring, H. Improving the energy performance of UK households: Results from surveys of consumer adoption and use of low- and zero-carbon technologies. *Energy Effic.* **2008**, *1*, 149–166. [CrossRef]
9. Kaenzig, J.; Wüstenhagen, R. Understanding the green energy consumer. *Mark. Rev. St. Gall.* **2008**, *25*, 12–16. [CrossRef]
10. Sidiras, D.K.; Koukios, E.G. Solar systems diffusion in local markets. *Energy Policy* **2004**, *32*, 2007–2018. [CrossRef]
11. Klepacka, A.M. Significance of renewable energy sources in sustainable development. *Ann. Pol. Assoc. Agric. Agribus. Econ.* **2019**, *XXI*, 55–64. [CrossRef]
12. Arkesteijn, K.; Oerlemans, L. The early adoption of green power by Dutch households. *Energy Policy* **2005**, *33*, 183–196. [CrossRef]
13. Litvine, D.; Wüstenhagen, R. Helping "light green" consumers walk the talk: Results of a behavioural intervention survey in the Swiss electricity market. *Ecol. Econ.* **2011**, *70*, 462–474. [CrossRef]
14. Ek, K.; Matti, S. Valuing the local impacts of a large scale wind power establishment in northern Sweden: Public and private preferences toward economic, environmental and sociocultural values. *J. Environ. Plan. Manag.* **2015**, *58*, 1327–1345. [CrossRef]
15. Gerpott, T.J.; Mahmudova, I. Determinants of price mark-up tolerance for green electricity–lessons for environmental marketing strategies from a study of residential electricity customers in Germany. *Bus. Strateg. Environ.* **2010**, *19*, 304–318. [CrossRef]
16. Wüstenhagen, R.; Bilharz, M. Green energy market development in Germany: Effective public policy and emerging customer demand. *Energy Policy* **2006**, *34*, 1681–1696. [CrossRef]
17. Kesari, B.; Atulkar, S.; Pandey, S. Consumer Purchasing Behaviour towards Eco-Environment Residential Photovoltaic Solar Lighting Systems. *Glob. Bus. Rev.* **2021**, *22*, 236–254. [CrossRef]
18. Pandey, S.; Kesari, B. Consumer purchase behaviour of solar equipments: Paradigm shift towards the ecological motivation among rural working consumers in developing countries. *J. Adv. Res. Dyn. Control Syst.* **2018**, *10*, 363–375.
19. Sigrin, B.; Pless, J.; Drury, E. Diffusion into new markets: Evolving customer segments in the solar photovoltaics market. *Environ. Res. Lett.* **2015**, *10*, 084001. [CrossRef]
20. Dubois, G.; Sovacool, B.; Aall, C.; Nilsson, M.; Barbier, C.; Herrmann, A.; Bruyère, S.; Andersson, C.; Skold, B.; Nadaud, F.; et al. It starts at home? Climate policies targeting household consumption and behavioral decisions are key to low-carbon futures. *Energy Res. Soc. Sci.* **2019**, *52*, 144–158. [CrossRef]
21. Ameli, N.; Brandt, N. Determinants of households' investment in energy efficiency and renewables: Evidence from the OECD survey on household environmental behaviour and attitudes. *Environ. Res. Lett.* **2015**, *10*, 044015. [CrossRef]
22. Michelsen, C.C.; Madlener, R. Homeowners' preferences for adopting innovative residential heating systems: A discrete choice analysis for Germany. *Energy Econ.* **2012**, *34*, 1271–1283. [CrossRef]
23. Niamir, L.; Ivanova, O.; Filatova, T.; Voinov, A.; Bressers, H. Demand-side solutions for climate mitigation: Bottom-up drivers of household energy behavior change in the Netherlands and Spain. *Energy Res. Soc. Sci.* **2020**, *62*, 101356. [CrossRef]
24. Mills, B.; Schleich, J. Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries. *Energy Policy* **2012**, *49*, 616–628. [CrossRef]
25. Zhai, P.; Williams, E.D. Analyzing consumer acceptance of photovoltaics (PV) using fuzzy logic model. *Renew. Energy* **2012**, *41*, 350–357. [CrossRef]
26. Myojo, S.; Ohashi, H. Effects of consumer subsidies for renewable energy on industry growth and social welfare: The case of solar photovoltaic systems in Japan. *J. Jpn. Int. Econ.* **2018**, *48*, 55–67. [CrossRef]

27. Wolske, K.S.; Todd, A.; Rossol, M.; McCall, J.; Sigrin, B. Accelerating demand for residential solar photovoltaics: Can simple framing strategies increase consumer interest? *Glob. Environ. Chang.* **2018**, *53*, 68–77. [CrossRef]
28. Schelly, C. Residential solar electricity adoption: What motivates, and what matters? A case study of early adopters. *Energy Res. Soc. Sci.* **2014**, *2*, 183–191. [CrossRef]
29. Klepacka, A.M.; Florkowski, W.J.; Meng, T. Clean, accessible, and cost-saving: Reasons for rural household investment in solar panels in Poland. *Resour. Conserv. Recycl.* **2018**, *139*, 338–350. [CrossRef]
30. Mundaca, L.; Samahita, M. What drives home solar PV uptake? Subsidies, peer effects and visibility in Sweden. *Energy Res. Soc. Sci.* **2020**, *60*, 101319. [CrossRef]
31. Colasante, A.; D'Adamo, I.; Morone, P. Nudging for the increased adoption of solar energy? Evidence from a survey in Italy. *Energy Res. Soc. Sci.* **2021**, *74*, 101978. [CrossRef]
32. Noll, D.; Dawes, C.; Rai, V. Solar Community Organizations and active peer effects in the adoption of residential PV. *Energy Policy* **2014**, *67*, 330–343. [CrossRef]
33. Kowalska-Pyzalska, A. An empirical analysis of green electricity adoption among residential consumers in Poland. *Sustainability* **2018**, *10*, 2281. [CrossRef]
34. Van der Werff, E.; Steg, L.; Keizer, K. It is a moral issue: The relationship between environmental self-identity, obligation-based intrinsic motivation and pro-environmental behaviour. *Glob. Environ. Chang.* **2013**, *23*, 1258–1265. [CrossRef]
35. Barbarossa, C.; De Pelsmacker, P. Positive and Negative Antecedents of Purchasing Eco-friendly Products: A Comparison Between Green and Non-green Consumers. *J. Bus. Ethics* **2016**, *134*, 229–247. [CrossRef]
36. Mutum, D.S.; Ghazali, E.M.; Wei-Pin, W. Parallel mediation effect of consumption values and the moderation effect of innovativeness, in predicting the influence of identity on green purchasing behavior. *J. Consum. Behav.* **2021**, *20*, 827–844. [CrossRef]
37. Tagliapietra, S.; Zachmann, G.; Edenhofer, O.; Glachant, J.M.; Linares, P.; Loeschel, A. The European union energy transition: Key priorities for the next five years. *Energy Policy* **2019**, *132*, 950–954. [CrossRef]
38. Hajdukiewicz, A.; Pera, B. zena International trade disputes over renewable energy—The case of the solar photovoltaic sector. *Energies* **2020**, *13*, 500. [CrossRef]
39. European Commission. *Renewable Energy Progress Report*; European Commission: Brussels, Belgium, 2020.
40. Gielen, D.; Boshell, F.; Saygin, D.; Bazilian, M.D.; Wagner, N.; Gorini, R. The role of renewable energy in the global energy transformation. *Energy Strateg. Rev.* **2019**, *24*, 38–50. [CrossRef]
41. Bianco, V.; Cascetta, F.; Nardini, S. Analysis of technology diffusion policies for renewable energy. The case of the Italian solar photovoltaic sector. *Sustain. Energy Technol. Assess.* **2021**, *46*, 101250. [CrossRef]
42. Grębosz-Krawczyk, M.; Zakrzewska-Bielawska, A.; Glinka, B.; Glińska-Neweś, A. Why do consumers choose photovoltaic panels? Identification of the factors influencing consumers' choice behavior regarding photovoltaic panel installations. *Energies* **2021**, *14*, 2674. [CrossRef]
43. Institute for Renewable Energy. *PV Market in Poland*; Institute for Renewable Energy: Warsaw, Poland, 2021.
44. Confente, I.; Scarpi, D.; Russo, I. Marketing a new generation of bio-plastics products for a circular economy: The role of green self-identity, self-congruity, and perceived value. *J. Bus. Res.* **2020**, *112*, 431–439. [CrossRef]
45. Belk, R.W. The ineluctable mysteries of possessions. *J. Soc. Behav. Personal.* **2010**, *6*, 17–55.
46. Sparks, P.; Shepherd, R. Self-Identity and the Theory of Planned Behavior: Assesing the Role of Identification with "Green Consumerism". *Soc. Psychol. Q.* **1992**, *55*, 388–399. [CrossRef]
47. Dermody, J.; Koenig-Lewis, N.; Zhao, A.L.; Hanmer-Lloyd, S. Appraising the influence of pro-environmental self-identity on sustainable consumption buying and curtailment in emerging markets: Evidence from China and Poland. *J. Bus. Res.* **2018**, *86*, 333–343. [CrossRef]
48. Dermody, J.; Hanmer-Lloyd, S.; Koenig-Lewis, N.; Zhao, A.L. Advancing sustainable consumption in the UK and China: The mediating effect of pro-environmental self-identity. *J. Mark. Manag.* **2015**, *31*, 1472–1502. [CrossRef]
49. Kashima, Y.; Paladino, A.; Margetts, E.A. Environmentalist identity and environmental striving. *J. Environ. Psychol.* **2014**, *38*, 64–75. [CrossRef]
50. Whitmarsh, L.; O'Neill, S. Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. *J. Environ. Psychol.* **2010**, *30*, 305–314. [CrossRef]
51. Smith, E.R.; Semin, G.R. Situated social cognition. *Curr. Dir. Psychol. Sci.* **2007**, *16*, 132–135. [CrossRef]
52. Chowdhury, M.; Salam, K.; Tay, R. Consumer preferences and policy implications for the green car market. *Mark. Intell. Plan.* **2016**, *34*, 810–827. [CrossRef]
53. Attaran, S.; Celik, B.G. Students' environmental responsibility and their willingness to pay for green buildings. *Int. J. Sustain. High. Educ.* **2015**, *16*, 327–340. [CrossRef]
54. Bei, L.; Simpson, E. The determinants of consumers' purchase decisions for recycled products: An application of acquisition transaction utility theory. *Adv. Consum. Res.* **1995**, *22*, 257–262.
55. Thorbjørnsen, H.; Pedersen, P.E.; Nysveen, H. "This is who i am": Identity expressiveness and the theory of planned behavior. *Psychol. Mark.* **2007**, *24*, 763–785. [CrossRef]
56. Ajzen, I.; Fishbein, M. *Understanding Attitudes and Predicting Social Behavior*; Cliffs, E., Ed.; Prentice-Hall: New York, NY, USA, 1980.
57. Ajzen, I. The theory of planned behavior. *Organ. Behav. Hum. Decis. Process.* **1991**, *50*, 179–211. [CrossRef]

58. Mohd Suki, N. Green product purchase intention: Impact of green brands, attitude, and knowledge. *Br. Food J.* **2016**, *118*, 2893–2910. [CrossRef]
59. Oliver, J.D.; Lee, S. Hybrid car purchase intentions: A cross-cultural analysis. *J. Consum. Mark.* **2010**, *27*, 96–103. [CrossRef]
60. Sheth, J.N.; Newman, B.I.; Gross, B.L. Why we buy what we buy: A theory of consumption values. *J. Bus. Res.* **1991**, *22*, 159–170. [CrossRef]
61. Lin, P.; Huang, Y.; Wang, J. Applying the theory of consumption values to choice behavior toward green products. In Proceedings of the 2010 IEEE International Conference on Management of Innovation & Technology, Singapore, 2–5 June 2010; pp. 348–353.
62. Sweeney, J.C.; Soutar, G.N. Consumer perceived value: The development of a multiple item scale. *J. Retail.* **2001**, *77*, 203–220. [CrossRef]
63. Mohd Suki, N.; Mohd Suki, N. Consumption values and consumer environmental concern regarding green products. *Int. J. Sustain. Dev. World Ecol.* **2015**, *22*, 269–278. [CrossRef]
64. Lin, P.-C.; Huang, Y.-H. The influence factors on choice behavior regarding green products based on the theory of consumption values. *J. Clean. Prod.* **2012**, *22*, 11–18. [CrossRef]
65. Zailani, S.; Iranmanesh, M.; Hyun, S.S.; Ali, M.H. Applying the theory of consumption values to explain drivers'willingness to pay for biofuels. *Sustainability* **2019**, *11*, 668. [CrossRef]
66. Jaderná, E.; Přikrylová, J. Green solutions in automotive industry. *Mark. Sci. Inspir.* **2018**, *13*, 2–11.
67. Wang, H.; Ma, B.; Bai, R. How does green product knowledge effectively promote green purchase intention? *Sustainability* **2019**, *11*, 1193. [CrossRef]
68. Sang, P.; Yao, H.; Zhang, L.; Wang, S.; Wang, Y.; Liu, J. Influencing factors of consumers' willingness to purchase green housing: A survey from Shandong Province, China. *Environ. Dev. Sustain.* **2020**, *22*, 4267–4287. [CrossRef]
69. Yue, B.; Sheng, G.; She, S.; Xu, J. Impact of Consumer Environmental Responsibility on Green Consumption Behavior in China: The Role of Environmental Concern and Price Sensitivity. *Sustainability* **2020**, *12*, 2074. [CrossRef]
70. Gleim, M.R.; Smith, J.S.; Andrews, D.; Cronin, J.J. Against the green: A multi-method examination of the barriers to green consumption. *J. Retail.* **2013**, *89*, 44–61. [CrossRef]
71. Padel, S.; Foster, C. Exploring the gap between attitudes and behaviour. *Br. Food J.* **2005**, *107*, 606–625. [CrossRef]
72. Vermeir, I.; Verbeke, W. Sustainable food consumption among young adults in Belgium: Theory of planned behaviour and the role of confidence and values. *Ecol. Econ.* **2008**, *64*, 542–553. [CrossRef]
73. Chen, Y.S.; Chang, C.H. Enhance green purchase intentions: The roles of green perceived value, green perceived risk, and green trust. *Manag. Decis.* **2012**, *50*, 502–520. [CrossRef]
74. Yadav, R.; Pathak, G.S. Young consumers' intention towards buying green products in a developing nation: Extending the theory of planned behavior. *J. Clean. Prod.* **2016**, *135*, 732–739. [CrossRef]
75. Tajfel, H. Social identity and intergroup behaviour. *Soc. Sci. Inf.* **1974**, *13*, 65–93. [CrossRef]
76. Bollinger, B.; Gillingham, K. Peer Effects in the Diffusion of Solar Photovoltaic Panels. *Mark. Sci.* **2012**, *31*, 900–912. [CrossRef]
77. Graziano, M.; Gillingham, K. Spatial patterns of solar photovoltaic system adoption: The influence of neighbors and the built environment. *J. Econ. Geogr.* **2015**, *15*, 815–839. [CrossRef]
78. Jager, W. Stimulating the diffusion of photovoltaic systems: A behavioural perspective. *Energy Policy* **2006**, *34*, 1935–1943. [CrossRef]
79. Gadenne, D.; Sharma, B.; Kerr, D.; Smith, T. The influence of consumers' environmental beliefs and attitudes on energy saving behaviours. *Energy Policy* **2011**, *39*, 7684–7694. [CrossRef]
80. Salazar, H.A.; Oerlemans, L.; van Stroe-Biezen, S. Social influence on sustainable consumption: Evidence from a behavioural experiment. *Int. J. Consum. Stud.* **2013**, *37*, 172–180. [CrossRef]
81. Lee, K. The Green Purchase Behavior of Hong Kong Young Consumers: The Role of Peer Influence, Local Environmental Involvement, and Concrete Environmental Knowledge. *J. Int. Consum. Mark.* **2010**, *23*, 21–44. [CrossRef]
82. Yoo, J.-J.; Divita, L.; Kim, H.-Y. Environmental awareness on bamboo product purchase intentions: Do consumption values impact green consumption? *Int. J. Fash. Des. Technol. Educ.* **2013**, *6*, 27–34. [CrossRef]
83. Rex, E.; Baumann, H. Beyond ecolabels: What green marketing can learn from conventional marketing. *J. Clean. Prod.* **2007**, *15*, 567–576. [CrossRef]
84. Hartmann, P.; Apaolaza Ibáñez, V.; Forcada Sainz, F.J. Green branding effects on attitude: Functional versus emotional positioning strategies. *Mark. Intell. Plan.* **2005**, *23*, 9–29. [CrossRef]
85. Groves, R.M.; Fowler, F.J.; Couper, M.P.; Lepkowski, J.M.; Singer, E.; Tourangeau, R. *Survey Methodology*; Wiley: New York, NY, USA, 2011.
86. Poland Population. Available online: https://countrymeters.info/en/Poland#population_2020 (accessed on 16 December 2020).
87. Norstat Panelbook. Available online: www.norstatgroup.com (accessed on 6 January 2021).
88. Baruch, Y. Response Rate in Academic Studies-A Comparative Analysis. *Hum. Relat.* **1999**, *52*, 421–438. [CrossRef]
89. Sakshaug, J.W.; Yan, T.; Tourangeau, R. Nonresponse Error, Measurement Error, and Mode of Data Collection: Tradeoffs in a Multi-mode Survey of Sensitive and Non-sensitive Items. *Public Opin. Q.* **2010**, *74*, 907–933. [CrossRef]
90. Armstrong, J.S.; Overton, T.S. Estimating nonresponse bias in mail surveys. *J. Mark. Res.* **1977**, *14*, 396–402. [CrossRef]
91. Werner, S.; Praxedes, M.; Kim, H.-G. The reporting of nonresponse analyses in survey research. *Organ. Res. Methods* **2007**, *10*, 287–295. [CrossRef]

92. Lee, M.K.O.; Turban, E. A trust model for consumer internet shopping. *Int. J. Electron. Commer.* **2001**, *6*, 75–91. [CrossRef]
93. Yoo, B.; Donthu, N. Developing and validating a multidimensional consumer-based brand equity scale. *J. Bus. Res.* **2001**, *52*, 1–14. [CrossRef]
94. Chan, R.Y.K. Determinants of Chinese consumers' green purchase behavior. *Psychol. Mark.* **2001**, *18*, 389–413. [CrossRef]
95. Jamrozy, U.; Lawonk, K. The multiple dimensions of consumption values in ecotourism. *Int. J. Cult. Tour. Hosp. Res.* **2017**, *11*, 18–34. [CrossRef]
96. Arvola, A.; Vassallo, M.; Dean, M.; Lampila, P.; Saba, A.; Lähteenmäki, L.; Shepherd, R. Predicting intentions to purchase organic food: The role of affective and moral attitudes in the Theory of Planned Behaviour. *Appetite* **2008**, *50*, 443–454. [CrossRef] [PubMed]
97. Khan, S.N.; Mohsin, M. The power of emotional value: Exploring the effects of values on green product consumer choice behavior. *J. Clean. Prod.* **2017**, *150*, 65–74. [CrossRef]
98. Gerbing, D.W.; Anderson, J.C. An updated paradigm for scale development incorporating unidimensionality and its assessment. *J. Mark. Res.* **1988**, *25*, 186–192. [CrossRef]
99. Hair, J.; Black, W.; Babin, B.; Anderson, R. *Multivariate Data Analysis*; Prentice-Hall: Upper Saddle River, NJ, USA, 2010.
100. Schumacker, R.E. *A Beginner's Guide to Structural Equation Modeling*; Routledge: London, UK, 2012; ISBN 9780203851319.
101. Fornell, C.; Larcker, D.F. Evaluating structural equation models with unobservable variables and measurement error. *J. Mark. Res.* **1981**, *18*, 39–50. [CrossRef]
102. Chang, S.J.; Van Witteloostuijn, A.; Eden, L. From the Editors: Common method variance in international business research. *J. Int. Bus. Stud.* **2010**, *41*, 178–184. [CrossRef]
103. Podsakoff, P.M.; MacKenzie, S.B.; Podsakoff, N.P. Sources of method bias in social science research and recommendations on how to control it. *Annu. Rev. Psychol.* **2012**, *63*, 539–569. [CrossRef] [PubMed]
104. Thakkar, J.J. Introduction to Structural Equation Modelling. In *Studies in Systems, Decision and Control*; Springer: Singapore, 2020; pp. 1–11.
105. Pickett-Baker, J.; Ozaki, R. Pro-environmental products: Marketing influence on consumer purchase decision. *J. Consum. Mark.* **2008**, *25*, 281–293. [CrossRef]
106. Mannetti, L.; Pierro, A.; Livi, S. Recycling: Planned and self-expressive behaviour. *J. Environ. Psychol.* **2004**, *24*, 227–236. [CrossRef]
107. Ecker, F.; Hahnel, U.J.J.; Spada, H. Promoting decentralized sustainable energy systems in different supply scenarios: The role of autarky aspiration. *Front. Energy Res.* **2017**, *5*, 14. [CrossRef]

energies

Article

Restructuring of the Coal Mining Industry and the Challenges of Energy Transition in Poland (1990–2020)

Jarosław Kaczmarek *, Konrad Kolegowicz and Wojciech Szymla

Department of Economics and Organization of Enterprises, Cracow University of Economics, Rakowicka St. 27, 31-510 Cracow, Poland; kolegowk@uek.krakow.pl (K.K.); szymlaw@uek.krakow.pl (W.S.)
* Correspondence: kaczmarj@uek.krakow.pl

Abstract: The European Union's climate policy and the energy transition associated with it force individual countries, their economies and their industrial sectors to carry out thorough changes, often of a deep, high-cost and restructuring nature. The aim of the article is to provide a multidimensional assessment of the forms and effects of the restructuring of coal mining companies in Poland in light of the current energy transition process. The research problem is encapsulated within the following two interdependent questions: Has the restructuring process allowed the coal mining industry to achieve sufficient efficiency to sustainably compete in the open market, and to what extent, if at all, have the objectives of restructuring been achieved from the perspective of changes in the energy mix? The research covers all coal mining companies included in the official statistics. It adopts a long-term perspective (1990–2020), dating from the beginning of the systemic transformation in Poland. The research involved the use of multivariate financial analysis methods, including the logit model for predicting the degree of financial threat, as well as taxonomic methods for assessing the dissimilarity of structures and their concentration. The general conclusion of the research is that there has been a lack of consistency (follow-up) between the forms and effects of restructuring in coal mining companies in Poland on the one hand and changes in the composition of the country's energy mix as a result of the energy transition on the other. In particular, this means that such restructuring, being neither effective nor efficient, has failed to accelerate change in the energy mix.

Keywords: restructuring; energy policy; hard coal mining; energy transition

Citation: Kaczmarek, J.; Kolegowicz, K.; Szymla, W. Restructuring of the Coal Mining Industry and the Challenges of Energy Transition in Poland (1990–2020). *Energies* **2022**, *15*, 3518. https://doi.org/10.3390/en15103518

Academic Editor: Ben McLellan

Received: 10 April 2022
Accepted: 9 May 2022
Published: 11 May 2022

1. Introduction

The countries of the European Union are characterised by different structures of electricity production, differing availability of fossil fuels and different states of advancement in the use of renewable energy sources [1,2]. Poland is an example of a country with significant coal resources and a still high degree of dependence in terms of electricity production on hard coal and lignite. Therefore, one of the biggest challenges in the ongoing energy transition in Poland is the restructuring of the hard coal mining sector. Dealing with this challenge requires an extensive, long-term analysis of the directions and effects of the changes already made in this sector. Objective diagnosis of former achievements may become the basis for building policies and programs for simultaneous restructuring of the coal mining and energy sectors.

In the article, the research problem focuses on identifying consistency (follow-up) between the forms and effects of restructuring of coal mining companies in Poland on the one hand and changes in the composition of the country's energy mix on the other. This problem, in turn, provided the main platform for the research goals, namely a multidimensional assessment of the forms and effects of such restructuring in the context of the ongoing energy transition. This main goal is made more specific by the five sub-goals.

Therefore, the key questions posed in the research are as follows: has restructuring enabled the hard coal mining industry to reach a sufficient level of efficiency to compete on a sustainable basis on the open market, and to what extent, if at all, were the assumed restructuring objectives achieved in the context of changes in the energy mix? These questions, in turn, determine whether the content of the main research hypothesis is verified. The main hypothesis was supported by three partial hypotheses (see Section 1.5).

The research conducted in the present article led to the general conclusion that there was a lack of coherence (follow-up) between the forms and effects of the restructuring of coal mining companies in Poland on the one hand and changes in the energy mix as a result of energy transition on the other. More specifically, this means that such restructuring, being inefficient did not accelerate change in the energy mix. Coal mining companies have not achieved sustainable profitability and competitiveness on the open coal market. Restructuring did not bring about any significant changes in the structure of employment, assets, capital expenditure or sales, nor did it trigger major technical and technological progress. The effects of restructuring revealed a number of important temporal caesura in this process, thanks to which it can be divided into different periods. The changes observed in the energy mix occurred as a result of having to cover higher energy demand with the increased use of non-carbon energy sources.

The methodology and results of the research as well as a discussion of its findings provide the structure of the article. In the first step, the results of the literature and a previously known research review are presented. The authors also define the relationships between the following triad of terms: transformation, structural changes and restructuring, and the research problem is embedded in an international context (restructuring of coal mining in EU countries), after which the research goals, hypothesis and methods forming the research framework are presented. The research results themselves have been arranged in order, beginning with an analysis of the degree of implementation of the restructuring objectives, followed by a cause-and-effect analysis of the results, concluding with an analysis of changes in the structures and analysed relationships. In the next step, the results were discussed in depth, which provided further confirmation of the research hypotheses. The final conclusions are presented in the summary.

The article is part of a series of publications on the restructuring and development of enterprises and industries with particular emphasis on the fuel and energy sector. The current research is a diagnosis of the state of dependence (follow-up/consistency) of the effects of coal mining restructuring and changes in the energy sector. The next stage will include a comparative analysis of the effectiveness limits (relation of effects and inputs) of all energy generation sources. Combining the current diagnosis with such an efficiency analysis (non-parametric approach) will allow for the formulation of the main elements of the new energy transition policy.

1.1. Restructuring and Structural Changes

In the present article, restructuring is treated as a different phenomenon from structural change. The year 1990 marked the beginning of the implementation in Poland of a set of reforms aimed at systemic transformation, including economic transformation [3] (pp. 102–103). It is commonly believed that the transformation positively contributed to economic development [4–6]. It was supported by structural changes, the factors and growth-related dependencies of which created a paradigm in economics [7] (pp. 10–18). These changes, induced by the transformation, gradually turned into autonomous processes [8] (pp. 45–54), [9,10].

In the above context, transformation involves the reconstruction of the structure of the economy, and restructuring, as an integral element the former, has become one of the levels of transformation in Poland [11] (p. 153). Generally speaking, restructuring concerns changes taking place in economic structures such as enterprises (a micro approach). As regards internal development opportunities, these fundamental, external factors have destabilised enterprises [12] (p. 114). To regain their equilibrium, enterprises have had to adjust [13] by adopting restructuring strategies [14] (pp. 260–269), [15] (pp. 391–397). Their goal is to eliminate discrepancies between changes in the environment and the path of an enterprise's development. However, not only must they adapt to such changes, but they must also anticipate them [16] (pp. 50–62), [17] (pp. 81–92), [18] (pp. 301–308).

In its essence, restructuring is a multi-faceted and complex process [19–21]. The effects of restructuring are not immediately felt, but rather are spread out over time [22] (pp. 10–23), [23]. A distinction should be made between inputs that are primary and effects that are secondary [24]. The effects of restructuring are not always positive either [25].

As was noted above, the aim of a company's restructuring is to adapt to a changing environment. The future state or states of this environment are undefined and cannot be predicted with any certainty. As a consequence, an enterprise operates with an element of risk, and the sublimation of such a critical state constitutes a crisis for an enterprise [26,27] (pp. 42–48). Enterprises are exposed and vulnerable to a diverse range of risks, and this is especially true of Polish enterprises [28] (pp. 10–31). An open crisis usually results from a long-lasting "smouldering" crisis, i.e., from the accumulation of causes that are not neutralised and which assume a structural, systemic form. The symptoms of a company in crisis, which themselves constitute an interplay of various factors, are reflected in its performance, and ultimately in its results and financial condition [29]. At the present time, these are detected using early warning systems [30], which make use of discriminant analysis methods [31], in particular logit models [32] (pp. 60–74). Such a model was estimated for the present research.

The purpose of assessing structural changes in this article was to quantify not only the scale of changes that take place within particular structural components, but also to determine the degree of structural transformation over time [33]. Economic structures comprise sets of elements in the economic process together with the specific relationships that exist between them [34]. These can be mapped out based on the convergence between the numbers corresponding to these elements [35]. The main goal of measuring structural changes is to determine the absolute and relative differences between the shares of individual structure components in the whole [36] and the total impact of such changes at moments in time on the same or many different objects [37]. The task of analysing structural changes is to show the course and size of structural transformations as well as the dynamics of these changes, and also to identify the structural components that influence these changes [38]. The intensity of structural change was further assessed by determining its course, i.e., by measuring the factor of concentration (absolute concentration).

1.2. Restructuring of Coal Mining in Europe

Alongside the intensive mining of hard coal, in the years after World War II, mining countries such as Poland also embarked on a period of industrialisation and intensive development. In 1990, England, France, Germany, Belgium and Poland accounted for 90% of all coal extracted in Europe, with Poland producing 56% of the total. However, by 2020, its share had reached 96%. The turning point in the mining industry came in the second half of the 20th century, when oil rapidly overtook coal in economic importance. From that time, restructuring of the coal mining industry in Europe began in haste. Each country has adopted its own different approach based on different tools, the use of which was, and still is, conditioned by many internal and external factors [39].

In France, from 1960 onwards, the government began to pursue a policy aimed at increasing the share of nuclear energy in electricity output, thereby reducing the demand for domestic thermal coal. This change had the direct effect of reducing employment. Despite the fact that the mining industry in France had been owned by the state since 1946, social and regional factors prevented the French government from completely shutting down the mining industry, which only occurred in 2004 (finally two years later in Decision 3632/93/ECSC of the European Coal and Steel Community).

In Belgium, coal mining had been privately owned, but in 1967 the government nationalised the coal industry and embarked on its restructuring. The closure of the mines caused serious social tensions, but production costs were very high, and Belgian coal was unable to compete with imported coal. In addition, there was a high dependence on foreign labour. The restructuring plan provided mainly for the reduction of employment, and eventually over 10,000 employees decided to leave and rely on redundancy schemes. By 1989, employment had dropped to 6000 people, and the second stage of restructuring came to an end with the closure of the country's last mine in 1992.

In the case of England, coal was replaced by oil as the main source of energy back in the 1960s, while nuclear energy and natural gas began to develop rapidly [40]. The end of the oil crisis (1979) and Margaret Thatcher's ascension to office ushered in the era of what came to be known as "state business" [41]. The country's least profitable mines began to be closed. The aim of restructuring was to make mining more competitive through its mechanisation, cut employment and introduce a business model specifically suited to private enterprises [42]. The end result was the complete privatisation of the mining industry, which had been concluded by 1994. In 2019, the decision was taken to close the country's last colliery, although this did not signal a definitive end to mining in England [43]. In 2020, the government approved the construction of the first new deep-sea coal mine in 30 years [44].

The German coal industry entered a period of crisis in the early 1960s [45]. The federal and regional authorities (the Ruhr region) pursued a consistent policy aimed at increasing productivity. In 1968, a comprehensive restructuring program was launched to adjust the volume of output to shrinking needs and introduce extensive social protection programmes [46]. In the early 1990s, pressure from the European Commission to cut enormous public aid allocated to mining together with forecasts of a decline in demand forced more radical restructuring. The last mines were closed by 2018 [47]. The restructuring path adopted by Germany, which was almost painless, was extended over time and guaranteed social peace, and as a consequence differed from the more drastic steps taken to liquidate the mining industry in Great Britain, which suffered widespread social protests as a result.

In Spain, following the gradual shrinking of the coal mining industry in 1950–1975, the industry enjoyed a period of rapid growth. Government endeavoured to regulate production volume, coal prices and energy sales. The Third National Energy Plan, implemented in 1984, provided for a further increase in coal mining and government subsidies. After Spain joined the EU, pressure increased to reduce subsidies to the coal industry. A plan to cut employment and mining activity was implemented in 1985 and continued into the 1990s, also as a consequence of pressure from the environmental lobby against mining from opencast mines. As a result, by 2020, only one small mine was in operation in Spain.

At the present time, Germany (with a share of 33.3%), France (8.8%), Spain (4.5%) and the United Kingdom (5.1%) are the leading coal importers in Europe and are beginning increasingly to appreciate the role of this raw material in shaping their energy security.

The restructuring of the hard coal mining industry in Poland has been ongoing since 1989, that is, from the beginning of the systemic transformation and the transition to a market economy [48] (p. 242). Currently, Poland faces the challenge of creating a long-term energy policy that will ensure a balance between the security of its energy supplies, the efficiency of economic processes and an appropriate standard of environmental protection [49]. According to the plan, hard coal mining in Poland will come to an end by 2049 (restructuring programs are discussed together with an assessment of the achievement of the objectives in Section 3.1).

1.3. Poland's Energy Transition and Its Implications

The Polish energy sector is primarily based on the combustion of hard coal and lignite. According to Eurostat databases [50] (all data concerning the structure of electricity generation in Poland and EU countries comes from Eurostat databases) regarding energy in 1990, 96% of electricity and derived heat was produced using coal (56% from hard coal and 40% from lignite). In 2020, this fuel source still accounted for 68% of the country's electricity supply (44% from hard coal and 24% from lignite), which represents a decrease of 28 pp..b.

Electricity generation was completely different in form in the "Old Union" (EU15). In these countries, electricity obtained from coal accounted for only 35% of total output in 1990, and less than 8% in 2020. It should be emphasised, however, that in the case of the EU15, restructuring of the mining industry was completed earlier or is currently at an advanced stage (see Section 1.3). Of course, we need to be aware that these countries have diversified access to fossil fuels, including coal. As a result, in the years 1990–2020, these countries underwent more profound changes than Poland in terms of their energy mix. During this period, although the share of nuclear energy decreased from 33% to 25%, the share of renewable energy sources increased from 14% to 42%, and the share of natural gas rose from 7% to 22%. Therefore, it can be argued that, compared to the EU15 countries, Poland is an example of a country that has failed to adapt to the requirements of energy transition [51] (p. 10).

In this context, however, it is worth looking at the situation in those countries that were admitted to the European Union alongside Poland as part of its fifth enlargement (EU11). In the case of these countries, in 1990, coal accounted for 55% of total electricity generated, and in 2020, its share still remained at 39%. Thus, progress in reducing the importance of coal (by 16 pp.) in the EU11 countries has been slower than in Poland. It should also be noted that in 1990, the share of nuclear energy in the energy mix of many of these countries was significant, amounting on average to 17.5%, and by 2020 this share was as high as 22%. In turn, the share of energy from natural gas increased in this period from 10% to 12%, and from renewable energy it had risen from less than 7% to reach 23%.

The above observations lead to the conclusion that Poland does not differ significantly from other EU11 countries when it comes to the pace of change in its energy mix during this period [52]. Of course, this does not constitute grounds for a generally positive assessment in light of the delays in transformation observed in this group of countries. The reasons for this delay can partly be found in the insufficient financial resources allocated to the transformation, but also, as in the case of Poland, in the considerable influence exerted by the social and political environment [53].

Despite the fact that coal continues to account for a high share of Poland's energy mix, for the most part it is the process of adapting to EU requirements that had, and still has, a decisive influence on the country's energy policy, and thus on a gradual reduction in the share of coal [54]. The foundations of energy sector reform and the energy transition in Poland in general are, primarily, the following:

- the process of adapting Polish law to the legislation of the European Union as part of pre-accession negotiations (since 1998) [55],
- the assumptions of the accession treaty obliging Poland to adopt a number of energy and climate directives in force in the Union (including, inter alia, the obligation to reduce emissions [56] and increase the share of renewable energy sources (RES) in its energy mix to 7.5% by 2010 [57]),
- the Energy and Climate Package [58] launched in 2008, which includes the "20-20-20 Program", obliging EU countries, inter alia, to reduce greenhouse gas emissions by 20% compared to 1990 and increase their share of renewable energy sources to 20% of primary energy by 2020 [59,60],
- further packages resulting from arrangements reached at the "climate summits" (including the "Paris Agreement [61]—2015 and the so-called "winter package" [62]—2016), which set even more ambitious targets in terms of emissions and the share of renewable energy sources,
- the European Green Deal (COM/2019/640-2019) [63] and its development—the "Fit for 55 package" (COM/2021/550-2020 and 2021) [64].

Along with these arrangements, subsequent phases in the European Emissions Trading System (EU ETS) introduced in 2003 by Directive 2003/87/EC [65] have also been implemented, which in the following years would have a significant impact on the profitability of energy production from conventional sources [66].

Returning to our assessment of changes in the structure of electricity generation sources in Poland, it should be emphasised that although they have been significant in the case of coal (a decrease of 28 pp, i.e., by 29.1%), in absolute values, in the case of actual coal consumption, these changes are no longer so great. According to Eurostat data, in the years 1990–2020, the consumption of coal in the power industry decreased by only 9%. This means that the changes in the energy mix were achieved by covering the increase in energy demand (rising by 16%) through the greater use of non-coal energy sources (8.5 times). This was the case primarily with natural gas (a 16-fold increase) and renewable energy (a 15-fold increase). The use of gas was characterised by large fluctuations connected with the dates when large and medium-sized power plants and combined heat and power plants were commissioned. Gas consumption increased at its fastest rate in the years 1998–2005 (average annual growth of 49%) and in 2015–2020 (average annual growth of 22%). Renewable sources developed much later (apart from the existing large, commercial hydropower plants), with wind playing the most important role. The beginnings of the wind energy sector date back to 1997, but it only began to develop on a larger scale from 2001 onwards (average annual growth of 50%). The most rapidly developing renewable source is photovoltaics, the origins of which in Poland date back to 2011 (average annual growth of 182%), and the annual maximum occurred in 2015 (722%).

To sum up, the position enjoyed by coal as the strategic anchor of Poland's energy security has undoubtedly been unshakeable for decades [67]. This was very much confirmed by the findings of successive documents setting out Poland's energy policy (PEP) over the next decades [68–71]. These policies (adopted in 1990, 1995, 2000 and 2005, respectively) predicted that demand for hard coal and lignite for the energy sector would remain at a similar level or even increase. Moreover, some of these forecasts (PEP 2020, PEP 2025) were based directly on findings from previously approved mining reform programs. This leads to the thesis that the country's energy policy is dependent on the assumptions of reform of only one sector of the economy, i.e., mining. Only the energy policy adopted in 2009 (PEP 2030) [72] anticipated a significant and steady decline in the use of hard coal and lignite in electricity production. According to forecasts, the consumption of hard coal in 2020 would be nearly 30% lower than the 2006 base, and lignite consumption would decline by 26%. Therefore, such a significant reduction in coal consumption should have resulted in a reduction in output in domestic mines and thus have constituted a strong impulse for their restructuring.

1.4. Identified Research Deficits

The problem of the energy transition has been at the forefront of the European Union's policy in the recent years. The adaptation of economies and industry to changing climate goals is the leitmotif of many scientific and expert studies of a cross-cutting nature. They concern the analysis of changes in all EU countries or groups thereof [73–75], or locally concern only individual countries, including, for example, Germany [46], Spain [76] and Denmark [77]. The object of similar research was and still is also Poland. So far, detailed studies have focused on the determinants of the energy transition and its pace [78], its costs [79] or its impact on individual industry sectors [80].

The fact that Poland is a traditionally hard coal mining country forces research on the restructuring process of the entire coal mining industry and individual mining companies.

Previous studies have strongly touched upon the theoretical aspect of the mining restructuring process and the creation of restructuring programs [81]. The research was limited only to a review (qualitative description) of newly created and already implemented programs [82]. Sometimes, they only reviewed the objectives, legitimacy and complementarity of the tasks performed [83]. To some extent, the research also concerned the assessment of the degree of implementation of mining restructuring programs. However, it was carried out only from the perspective of assessing the assumed effects [84], sometimes also in relation to political conditions [85]. The research conducted so far has attempted to periodise the restructuring process, but its basis was only the periods derived from legal acts and related to subsequent programs. Such a division did not take into account endogenous factors and interdependencies between them. Many times, the authors of publications focused on the basic production, technical, economic [86] and financial [87] indicators and their absolute change [88]. However, they have not developed and used any multidimensional, discriminatory models. This is a strong deficit, especially regarding the high rank of these models (especially logit ones) and the intense growth of interest in their application. Moreover, no studies concerned changes in economic structures and the assessment of their impact on the measures as dependent variables [89]. The analysis of mining enterprises [90] so far has focused mainly on the assessment of changes in employment [91,92] or changes in sales and production [93]. These analyses, however, were fragmentary and did not take into account the complexity of the assessment of the complex restructuring process. A significant part of the publication focuses on the assessment of the technical conditions of extraction [94] and the assessment of changes in production parameters. Some authors have turned their attention to the designation of possible restructuring strategies [95,96] and assessed management actions [97]. However, their studies do not contain an analysis of the economic and financial effects of the restructuring measures taken. In the past, attempts have also been made to assess financial ratios [98], but only in absolute terms. Furthermore, there was no attempt to perform a comprehensive analysis and evaluation of changes using a synthetic model. Sojda [99] made such an attempt at statistical analysis, but in an isolated approach, concerning only a few, selected financial indicators. However, he did not analyse the cause-and-effect implications.

Each determinant as a category, relation or measure of the assessment of economic results and financial condition, being a target in restructuring programs, can be the basis for calculating the change in the structure that characterises it. Few studies, however, attempted such a detailed analysis, despite the fact that structural research is crucial for most scientific disciplines [100,101]. Usually, such research concerns only change in the structure of employment [102,103], investments, assets or sold production. However, there is no research on the directions of transformations, assessment of the dynamics (intensity) of structural changes and indication of those components of structures that intensify or anticipate the changes to the greatest extent. This is a significant deficit because restructuring is closely related to structural changes [104] (pp. 11–12), which restore the ability to develop [105]. This development concerns not only the potential (size), but especially the structures [106]. These are its components and determinants [107] (p. 19), which forces the necessity to fill this deficiency in the research on the complex structure of coal mining enterprises.

There is a particularly clear deficit in research at the interface between mining and energy transition. Although the issue of EU climate policy appears in the above-mentioned studies (especially in those published after 2008—the 3×20 climate and energy package), it usually constitutes only a research background. So far, the authors have not addressed the problem that can be described by the question: are the pace and effects of the restructuring of the coal mining sector sufficient from the point of view of the desired pace of energy transition? This problem is the focus of the research in this article.

The review of the literature revealed a number of significant research gaps at the theory-cognitive, methodological and empirical levels. In the first case, no parallel approach has been developed for assessing the course and effects of the restructuring of the coal mining industry and changes in the energy sector from the perspective of its transformation, and, as a consequence, changes in the energy mix. At the methodological level, there is clearly lacking a method for measuring structural changes in coal mining, as well as their direction and variability or their correlation with operational effectiveness. Moreover, until now, researchers have not used aggregated measures to assess a company's financial condition, which are the most specific barometers of its operational health. This concerns in particular indicators predicting the financial risk of a going concern. Nor has any comprehensive, multi-layered method been developed for assessing the effects of restructuring, based on the relationship between causes (operating economics) and effects (financial results), which is important from the point of view of assessing the mechanism by which these results are achieved. Meanwhile, at the empirical level, no research results have been published that cover a longer timeframe, i.e., the period from the beginning of the economic transformation in Poland (1990) up to the present day. Moreover, most of the available research results were obtained with the use of a research sample, which limits the formulation of general and universal conclusions regarding the coal mining sector as a whole.

1.5. Research Problem, Goals and Properties of Research

The research problem that emerges from the above-identified deficits is the consistency (follow-up) between the course and effects of the restructuring of coal mining companies in Poland and changes in the composition of the country's energy mix. It shows the main goal of the research, which is to provide a multidimensional assessment of the forms and effects of therestructuring of coal mining companies in the context of the ongoing energy transition. The main goal was achieved through the implementation of the following sub-goals:

- Measure the impact of key factors on the financial condition of coal mining companies,
- Aggregate the partial determinants of this financial condition as a basis for assessing the financial risk to a going concern (barometer),
- Gauge the impact of restructuring programs on organisational and structural changes in coal mining companies,
- Identify and measure the interdependence between structural changes and the effectiveness of coal mining companies' operations,
- Identify and measure the impact on production volume of changes in the structure of energy generation.

The research problem and research objectives are sublimated within the main hypothesis: (H) The effective and efficient restructuring of coal mining companies results in accelerated changes in the energy mix. This in turn gives rise to the following questions: has the restructuring carried out so far ensured a level of efficiency sufficient for the hard coal mining industry to compete on sustainable terms on the open market, and to what extent, if at all, have the objectives of restructuring been achieved in the context of changes in the energy mix?

The main hypothesis was supported by three partial hypotheses resulting from the partial goals and the "atomisation" of the research problem:

H1. *The restructuring of coal mining companies resulted in the achievement of the primary goal of sustainable profitability and increased productivity, with labour as the main factor*;

H2. *Hard coal restructuring has brought about significant changes in the structure of employment, assets, capital expenditure and sales*;

H3. *The effects of restructuring coal mining companies based on a multidimensional approach are determined by time intervals characterised by elements of homogeneity (time series periodisation)*.

The research covered all the enterprises included in the "Mining and coal mining" section of the PKD (PKD—Polish Classification of Activities). This constitutes an exhaustive compilation of all enterprises included in the official statistics. These are long-term studies and cover the period 1990–2020. These two factors provide a firm basis for formulating general conclusions and assessments that extend beyond the specific problem of the research sample. They also make it possible to identify real, and, as a consequence, long-term, trends and changes in structures as well as interdependencies (correlations) and regression relationships.

The research framework included two initial planes of inquiry, supported by appropriate methodological pillars. The first involved a multidimensional assessment of restructuring based on the features of a certain economic model. This model reveals the mechanism used by coal mining companies to achieve results, understood as a combination of causes (economics of operation) and effects (financial results). The second level of research provides insights into the intensity of changes in the structures of coal mining companies and their interdependence with changes in operating efficiency. The resulting third level of research consisted in assessing the effects and forms of restructuring of coal mining companies according to the degree of consistency with the effects of implementing the goals of energy transition examined in the two previous planes.

For the needs of the research goals, hypotheses and framework, numerous research methods were used, including versions of multivariate financial analysis, together with an estimated logit model for predicting the degree of financial risk to a going concern (a universal barometer of an enterprise's financial condition ensuring a dynamic measurement). In turn, to study changes in structures, the authors used taxonomic methods to assess the structural dissimilarities (changes in intensity) and their concentration. The occurrence of dependencies in terms of the economic effects of coal mining restructuring, changes in structures, efficiency and transition of the energy mix was investigated by means of statistical correlation and regression measures (see the Materials and Methods section).

The added value of the research lies in the following: (1) its uniqueness in terms of its subject (covering all the enterprises in the sector) as well as time (it is a long-term study, dating from the beginning of the economic transformation); (2) its use of a wide range of research methods (including logistic regression and structure taxonomy) and multi-layered analyses; (3) the fact that it assesses the coherence (follow-up) between the forms and effects of the restructuring of coal mining companies with changes in the energy mix resulting from energy transition. It is also important to emphasise the universality of both the methods used and in particular the structure of the RS—thanks to which it can be used in an international context (in coal-mining countries)—and thus also the universal applicability of the research itself and the comparability of the obtained results, something which had not been achieved previously.

2. Materials and Methods

The research presented in the article covered all enterprises included in the PKD classification section 10/5—"Mining and coal mining" (PKD—Polish Classification of Activities; PKD section 10 up until 2006 and PKD section 5 from 2007—a change in the classification). These are, for the most part, large, multi-plant enterprises. They constitute a full set of the enterprises included in the official statistics. The research was a long-term project, launched back in 1990 (the beginning of the economic transformation in Poland) and ending in 2020. As a consequence, they cover a period of 31 years, during which coal mining companies underwent deep and extensive restructuring. Thanks to the availability of comparable figures and information, the structural changes were assessed during the period 1992–2020 (for fixed assets from 2004).

As regards the ordering of the numerical data, it should be pointed out that the PKD section entitled "Mining and coal mining" classifies enterprises into two groups, i.e., hard coal mining and lignite mining. The former group occupies a dominant position in terms of the number of people it employs (95.9%), total assets (96.6%), sales revenues (96.7%) and net financial result (99.5%). This is due to the fact that lignite mines are a branch of energy companies (power plants), and only one small mine (operating to satisfy heating needs) functions as an independent enterprise. Generally speaking, this means that coal mining companies determine the results of the entire "Mining and coal extraction" section.

To provide a synthetic assessment of the financial condition of restructured coal mining enterprises, the author made use of a proprietary logit model [108] (Table 1), which was developed in response to the shortcomings of hitherto available models, i.e., their historicity (obsolescence), limited number of training sets and overestimated predictions, limitations in their application (dynamic measurements) and traditional estimation techniques (pairwise comparability only) [109] (pp. 31–42), [110]. The research did not apply any foreign models which had a suboptimal structure and which were inadequate with regards to the operating conditions of enterprises in Poland [111] (pp. 129–172).

The logistic regression models (logit models) are classic tools for predicting the degree of financial threat [112]. However, when compared to newer-generation methods (such as neural networks or random forests), they are more transparent and their results are easier to interpret and compare. In addition, those models in many cases achieve a comparable predictive ability [113]. Other advantages of the logistic regression model are the lack of assumptions on the probabilistic nature of explanatory variables and a user-friendly interpretation of the estimated model parameters.

The model was estimated on the basis of a training data set consisting of 13,047 active production companies and 1377 failed entities. These were all production enterprises covered by the official statistics in Poland (companies with more than 9 employees). The total number of observation objects for the years 2007–2012 amounted to 130,204. The companies were matched using the case-control technique [114] (pp. 145–162). The explanatory variables (out of a total of 29 financial indicators) were selected by means of step methods and the best subset method [115]. The criterion for assessing the fit of the model to the data was the AIC (Akaike Information Criterion) measure. The logistic regression model used was Firth [116,117]. This model involves changing the form of the standard likelihood function $L(\theta)$ to the form $L^*(\theta) = L(\theta)|I_\theta|^{1/2}$, where I_θ is the information matrix and θ is the vector of structural parameters [118]. This is the penalised likelihood function. Firth's logistic regression model has a Bayesian counterpart [119]. It is equivalent to the classical model with Jeffreys non-informative prior distribution superimposed on the parameters [120,121]. As a result of this modification, the estimation of the parameters in this model is almost unbiased (a particular improvement is observed in small samples), while the confidence intervals are characterised by better probabilistic properties. The predictive capacity of the model was measured using the sensitivity, specificity and the AUC (Area Under Curve) measure as the area under the Receiver Operating Characteristic (ROC) curve. The value of AUC = 0.914 confirms that the estimated model has very high predictive capabilities.

The measure derived from the model (FTD) expresses the degree of financial risk to a going concern and the danger of bankruptcy (annual advance, calibration against the bankruptcy rate, value given per 10,000 companies). It can be treated as a barometer of a company's financial condition [122,123]—the more favourable the situation, the lower the value of the FTD measure. In addition, it has two specific properties: it allows for a dynamic analysis and relativises its result in relation to the risk of bankruptcy.

Table 1. Estimated prediction logit model of the financial threat degree.

Financial Ratio Name (Predictor)	Predictor Symbol	Parameter Estimate
Intercept	-	−5.85
Operating return on assets	R_1	−1.231
Debt payment capacity	R_3	−0.492
Operating return on sales	R_6	−1.947
Total debt ratio	R_9	+0.62
Short-term liabilities cycle	R_{13}	+0.004
$\mathrm{FTD} = \frac{1}{1+\exp[-(-5.85+(-1.231\cdot R_1-0.492\cdot R_3-1.947\cdot R_6+0.62\cdot R_9+0.004\cdot R_{13}))]}\cdot 10000$		

Source: [124] (pp. 117–131).

To analyse the interdependence of time series (as well as regression interdependencies), a critical significance level of α = 0.05 was adopted, compared with a *p*-value test probability. A value lower than the critical level of significance means that one can proceed ad hoc, as if the null hypothesis that no correlation exists has been rejected. The degree of correlation as a numerical value is given in the text only when the condition of *p*-value < α is met. Detailed results of the regression analysis are provided in Appendix C. The correlation was measured using the Pearson r coefficient (degrees of correlation: <0.1 slight; 0.1–0.3 weak; 0.3–0.5 average; 0.5–0.7 strong; 0.7–0.9 very strong; >0.9 an almost full correlation). The measure of variability applied was the standard deviation and the coefficient of variation (the ratio of the standard deviation to the mean).

A linear regression model was adopted to analytically illustrate the relationship between an explained (dependent) variable and an explanatory (independent) variable and to determine the nature of this relationship [125]. The choice of a linear regression model was based on its simplicity, expressed by the easy interpretability of the results. Nevertheless, before choosing the linear model, an analysis of the distribution of observations was carried out using scatter diagrams. The point clouds took on a pattern indicating their distribution with respect to a straight line. Moreover, the analysis of the variables did not reveal the existence of outliers that would interfere with the determination of this model. The fit for the regression equation was established using the determination coefficient R2 (fit levels: 0.0–0.5 unsatisfactory, 0.5–0.6 weak, 0.6–0.8 satisfactory, 0.8–0.9 good 0.9–1.0 very good).

In their detailed assessment of the potential and financial results of coal mining enterprises, the authors resorted to numerous indicators of financial analysis covering the following areas: potential, results, debt, financial liquidity, profitability, effectiveness, and efficiency. Because these are commonly known and have been widely described in the available literature on the subject, they are not explained in detail in the present article [126–128] (a general description is included in the Appendix A).

To assess structural changes, economic structures were used that enabled an evaluation of the transformations resulting from mining restructuring processes, i.e., regarding employment, net fixed assets, investment outlays, sales and the structure of electricity generation as an interdependent element. The intensity of change (NPS), also referred to as the degree of structural dissimilarity, was measured by means of a taxonomic approach. This made it possible to determine the absolute and relative differences between the shares of individual structural components and the total impact of these changes in the same or many different structural elements at comparable moments in time [129,130]. Using the taxonomy of structures, it is possible to determine, more unambiguously and comprehensively than by means of a traditional over time comparison of individual structural indicators, the degree of transformation of the structures under study and to carry out a periodisation of their development with regards to the criterion of the degree of intensity (dynamics) of structural changes [131]. Thus, taxonomy makes it possible to determine the directions of structural change [132], its dynamics (intensity) and its determinants (also as anticipation). In addition, it allows the evaluation of the similarity of structures to each other and over time.

$$NPS = 1 - \sum_{i=1}^{n} min(p_{i0}, p_{i1}) \tag{1}$$

where:

NPS—intensity of structural change (dissimilarity),

min—minimum value of the components of the structure,

p_{i0}—share of the i-th component of the structure in time t_0,

p_{i1}—share of the i-th component of the structure in time t_1.

The NPS measure assumes values in the range of $\langle 0, 1 \rangle$ where a value equal to zero means no structural changes while the value 1 denotes a complete change in the structure [133]. The NPS parameter makes it possible to determine the intensity of structural changes in relation to past periods, but not to determine the direction of change. The latter is gauged by means of the concentration measure, understood as the degree of deconcentration or consolidation of a given phenomenon in one component of the structure. For this purpose, the degree of structural concentration was measured by means of the Herfindahl-Hirschman index (HHI). The latter is calculated as the sum of the squared shares of all the components of the structure:

$$\mathrm{HHI} = \sum_{i=1}^{N} x^2 \tag{2}$$

where:

x—component share,

N—number of components.

The HHI index lies within the range of $\langle 0, 1 \rangle$. The higher the HHI value, the greater the concentration. It is calculated in such a way that the value of the components has a greater impact on the value of the HHI than their number [134].

3. Results

3.1. Extent to Which the Goals of Coal Mining Restructuring Programs in Poland Have Been Achieved

Coal mining companies in Poland were already being broken up and then commercialised in the first years of the systemic transformation. This strategy was expected to create competition on the market and give impetus to bottom-up restructuring [135]. These changes took place against a backdrop of top-down government coal pricing, the abolition of subsidies and, later, the introduction of temporary export restrictions, as well as barriers raised by new public laws. All these factors resulted in the systematic deterioration of the financial condition of mining enterprises, which soon gave rise to social unrest. To prevent escalation, successive governments took steps to improve the economic health of the mines. These actions were reflected in a number of government-sponsored mining restructuring programs. These steps were taken for various economic, social and political reasons [136]. In the years 1990–2020, nine programs, together with various modifications, were drawn up, adopted and implemented (a list of them is included in the Appendix B) [137].

An analysis of these restructuring programs reveals a radical shift in their main objectives, an increase in the number of specific objectives and a high degree of deconcentration. A reorientation was observed away from goals heavily focused on protecting mining companies from bankruptcy, towards the goals of privatisation, rationalisation of resource exploitation, profitability and energy security.

The general objective of restructuring was to ensure the independent, market-driven adjustment of coal mining companies to the conditions of a free market economy. This is because these concerns had been established during the years of a centralised economy characterised by an overdeveloped non-productive infrastructure, low levels of operating efficiency, high energy consumption and technological backwardness. The first steps were taken in May 1992. It was assumed that, when competing with each other, only a few inefficient mining enterprises would be liquidated. Unfortunately, the financial state of most mining enterprises deteriorated with each year that passed, leading to the financial collapse of 1998. In the years 1991–2002, none of the implemented mining restructuring programs achieved its main goal, that is, they failed to ensure the economic efficiency of the hard coal mining industry [138]. The reasons for this failure were, inter alia, unfavourable changes and structural dependencies between the main factors: employment, assets, capital expenditure, output and sales and electricity generation.

With the aim not only of saving mining enterprises from bankruptcy, but also of averting a crisis in an industrially important region of the country, the Polish government adopted the idea of consolidation. In 2003, the largest mining company in Europe (Kompania Węglowa S.A, Katowice, Poland) was established. Then, in 2015, the remaining mining concerns were merged with energy companies, while inefficient mines were transferred to a separate enterprise earmarked for liquidation (Spółka Restrukturyzacji Kopalń S.A., Bytom, Poland).

The year 2006 marked a particular turning point. Up until then, the rationalisation of employment was constantly listed among the specific objectives of each program, which was justified by the industry's high employment levels, which in turn was due to technological backwardness and an excessive focus on non-mining activities. In the first 6 years of restructuring alone, employment declined significantly (by approximately 41%, i.e., 140,000 employees), which, however, did not result in any social unrest. The post-2006 programs no longer provided for any cutbacks in employment, the more so as the employment level planned in the previous programs had only been achieved in two years, while in the remaining years, employment levels were slightly hight than the targets set.

The reasons for discontinuing employment reduction plans were as follows: [139,140]

- delays in organisational changes, in particular in the expected closure of mines in the first years of implementing such changes (1990–1994),
- generous redundancy packages, in particular in the form of financial incentives, which encouraged miners to change profession or take advantage of special mining leaves,
- an inadequate workforce due to an aging mining population and earlier job cuts,
- no investment-intensive policy aimed at upgrading machinery, supporting manual labour and promoting technical efficiency.

Overall, after 2006, restructuring programs no longer listed any specific measures [141]. Instead, these programs focused on the strategic directions of mining development, the aim of which was to set priorities in the strategies and action plans of enterprises. Natural breakdowns became a way to further reduce employment. Unfortunately, the unfavourable age structure of the industry (an "aging" workforce) was becoming an ever more acute problem. In 2008, employment increased in almost all employee groups (excluding administration employees).

The objective of the program for 2007–2010 was the rational and effective management of coal deposits. The employment policy pursued in 2007–2015 focused on optimising the use of internal reserves and ensuring the correct balance between wage increases and economic results. Council Decision No. 787 of the European Union of 10 December 2010, which limited the time allotted to supporting unprofitable mines and adopted increasingly restrictive standards regarding carbon dioxide emissions and environmental protection, had a decisive impact on the restructuring process. These solutions have become the core determinants shaping the functioning of the mining industry. In 2015, the government continued to assume that hard coal mining would be competitive in the new market conditions.

In April 2016, Polska Grupa Górnicza (PGG) was established to strengthen Poland's energy security [8] and function as a recovery plan for the failing Kompania Węglowa S.A. Another major crisis in the mining industry forced the government to conclude an agreement (24 September 2020) with trade unions and other interest groups and set 2049 as the final date for the closure of the mines.

The goal of most of the restructuring programmes was to make the mining industry profitable, but in only three programs was this actually the main objective (Table 1). The dominant features of all the programmes were the following: adjusting production capacity to demand, cutting mining costs, rationalising employment, increasing labour productivity and improving working conditions. All of them likewise envisaged a systematic reduction in production, mainly through the liquidation of highly inefficient mines, as well as those mines facing the most serious problems and natural hazards and thus incurring high output costs. The remaining goals of the restructuring programs involved changes in organisational structures, production volume and financial conditions. The former mainly involved privatisation, mining infrastructure and mine closures. Changes at the management level consisted in the creation of new supervisory structures. Changes in production resulted from a reduction in coal mining due to weaker demand, which in turn was a consequence of lower energy consumption in industry. Another important task was to restructure technological processes by modernising machinery and mining methods. Financial restructuring focused on improving profitability and reducing the indebtedness of mining enterprises. Efficiency was to be improved through investments in equipment and machines (longwall and road shearers or coal streams), as well as other equipment in the longwall complex in the form of powered supports, longwall conveyors and other devices (Table 2).

Table 2. Objectives and anticipated effects of the implementation of the hard coal mining restructuring programs in Poland in 1993–2020.

Objectives of the Programs/Programs	Programme I 1993	Programme II 1993	Programme III 1994–1995	Programme IV 1996–2000	Programme V 1998–2002	Programme VI 2003–2006	Programme VII 2004–2010	Programme VIII 2007–2015	Programme IX 2018–2030
Improving profitability, competitiveness, timely payment of liabilities									
Mitigating the effects of the current and planned restructuring of employment									
Protection of mining against collapse (debt reduction)									
Employment rationalisation, increase in labour productivity, improvement of working conditions									
Adaptation of production capacity, efficiency improvement, reduction of output costs									
Rational and effective management of coal beds									
Reducing the harmful effects on the natural environment									
Ensuring the country's energy security									
Privatisation of mining enterprises									
Optimisation of the organisational structures of the mining industry									
Diversification of coal use and maintaining export									
Vertical integration of mining and power industries									
Development of employee skills and innovations in mines									
Elimination of the negative effects of restructuring									
Maintaining the competitiveness of the mining sector									
The scope of planned coal sales (mill. Mg/year)	124–130	119–125	134–134	127–125	116–110	94–87	97–80	93–90	-
The planned Investment outlays (mill. PLN/programme)	588	-	1490	5488	5988	-	7921	2200	26,738
The scope of planned employment (thousand people, at the end of the year)	300	287	273–253	256–194	219–138	130–114	117	-	-
The scope of the planned capacity (Mg/employee/year)	437	-	463–515	508–529	525–773	725–806	795–810	-	-
The scope of the planned coal production (mill. Mg/year)	126–131	-	135–132	130–128	121–112	95–89	95–100	95–91	-

Notes: grey colour means main objectives, green colour specific objectives. Source: own study based on data from hard coal mining restructuring programs in Poland in the years 1993–2020 (Appendix B), materials of the Ministry of Economy. Available online: www.gov.pl (accessed on 2 February 2022).

3.2. Assessment of the Results of Coal Mining Enterprises

Partial hypothesis H1. *The restructuring of coal mining companies resulted in the achievement of the primary goal of sustainable profitability and increased productivity, with labour as the main factor.*

The overall results of coal mining companies in Poland in the years 1990–2020 were very poor. Accumulated revenues of PLN 729.6 billion generated a net profit of only PLN 1.1 billion, i.e., 0.15% (a weak correlation between results and revenues, i.e., r = 0.25). Until 1998, revenues grew rapidly, but costs increased at a much faster rate, which only exacerbated loses, despite essentially linear price growth. The subsequent suppression of costs yielded positive results that lasted until 2013 despite a resurgence in cost dynamics. Unfortunately, this trend continued despite worsening price conditions, which led to losses in 2014–2016. Costs have stabilised in recent years, and this trend has continued despite declining revenues, resulting in the highest ever annual losses (PLN—4.4 billion in 2020). The share of exports was subject to cyclical changes, with this share at its lowest when results had relatively stabilised, with an average, indeed for the most part negative, correlation with financial results (r = −0.45) (Figure 1).

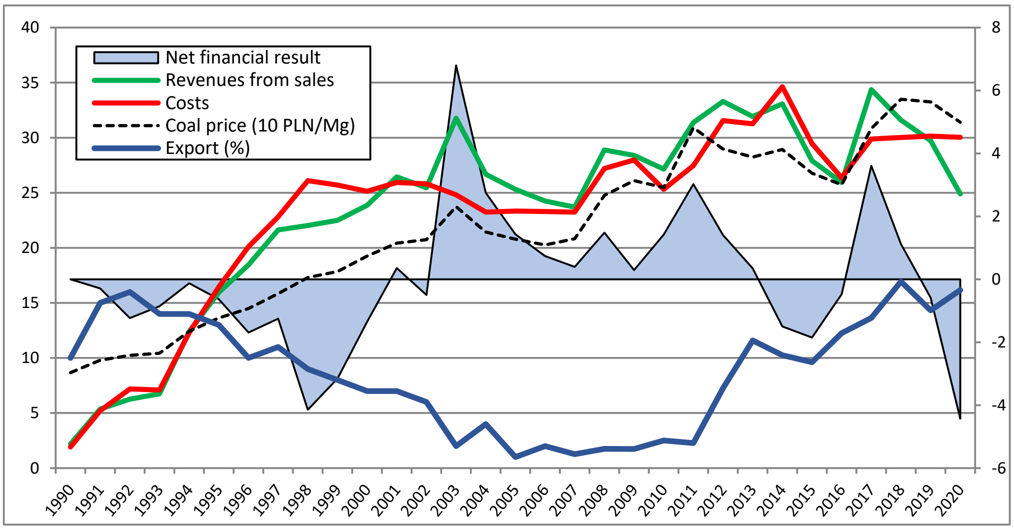


Figure 1. Financial results of coal mining enterprises in 1990–2020 (bn PLN). Note: net financial result and export—right axis. Source: authors' research based on GUS in Warsaw (Statistical Head Office in Warsaw, Poland)—databases of limited access. Available online: https://stat.gov.pl/en/databases/ (accessed on 4 February 2022); Pont Info Warsaw—Gospodarka SŚDP—commercial databases. Available online: http://baza.pontinfo.com.pl/index.php (accessed on 2 February 2022).

Labour costs accounted for constantly the largest share in the overall cost structure (average—41.9%, coefficient of variation 10.0%). Energy consumption costs remained relatively stable (average 5.7%), while the costs of materials decreased (average annual rate −1.9%, final share—10.0%) and the share of external services varied (average 19.0%, coefficient of variation 19.9%). Due to its dominant share in costs, the labour factor requires in-depth analysis.

The undoubted outcome of the restructuring of Polish coal mining companies in the years 1990–2020 was a reduction in employment, declining from 393,900 at the beginning of this period to 78,500 at its end. (−80.1%). Employment shrank by an average rate of −5.2%, with the most significant decline occurring up until 1998, and the process as a whole finished in 2016. Revenues from sales, varying periodically but increasing in the long-term, contrasted with a dwindling workforce, which resulted in higher labour productivity (an average annual rate of 14.4%), which collapsed just after 2016, based only on a reduction in the number of employees. However, unit labour costs are of greater importance when it comes to assessing how efficiently an enterprise's labour resources are being used. Unfortunately, this was not characterised by any upward trend (an average annual rate of −0.02%), and this measure of productivity remained relatively unchanged in 2020 compared to 1990. On average, therefore, PLN 100 in remuneration costs produced PLN 245.8 in sales revenues.

The main production and technical factor driving change in the coal industry was the volume of production. It decreased in an essentially linear fashion (average annual rate −3.3%), declining in total by 63.1%, and only in brief periods was it propped up by successive restructuring plans. An almost total correlation existed between this factor and the number of people employed in the industry (r = 0.96). In general, technical efficiency followed a similar path to that of labour, although at a much slower rate (average annual rate of 2.1%). What is especially noticeable is that after 2016, first technical efficiency and then labour efficiency deteriorated significantly. The correlation between technical efficiency and unit labour costs slightly exceeded the lower limit of the average (r = 0.39) (Figure 2).

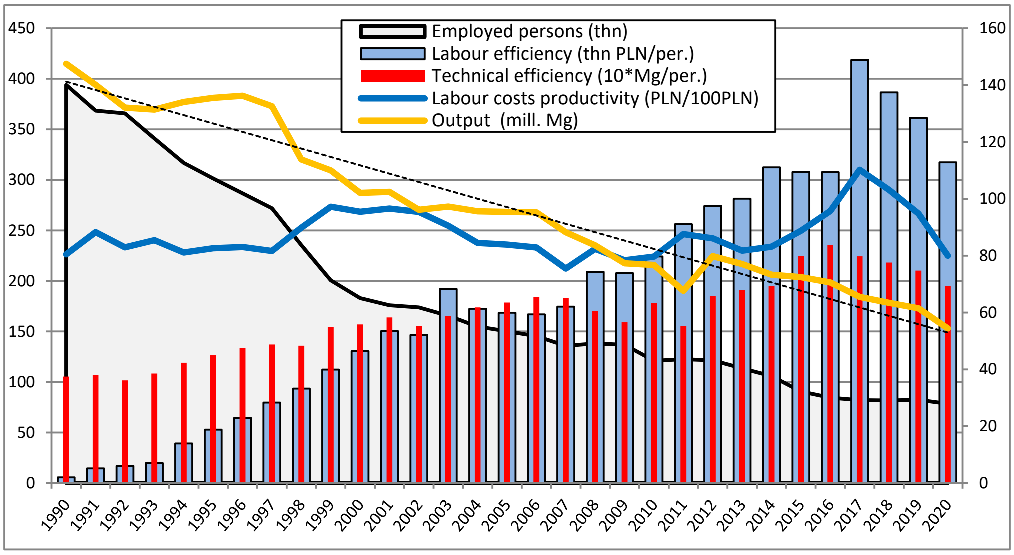


Figure 2. Employed persons, labour efficiency and labour costs productivity of coal mining enterprises in 1990–2020. Note: output and technical efficiency—right axis. Source: as in Figure 1.

Fixed and current assets grew fairly evenly until 2013, after which both declined. Investment expenditures increased linearly until 2011, but the ratio of investment expenditure to depreciation only increased in the years 1999–2011, after which the ratio decreased. By 2014, it was less than unity, so even a simple renewal of assets failed to be achieved. In the case of current assets, fluctuations intensified after 2011 as part of an overall upward trend, while, in general, receivables grew faster than inventories. Recently, a decline in receivables has brought about a reduction in short-term liabilities, but at the same time a disproportionate increase in receivables.

The period up until 2002 saw an alarmingly rapid increase in debt, especially short-term debt, which rose above what was deemed a safe level of liquidity at which liabilities can be settled. Moreover, ever higher losses led to negative equity in the years 1999–2002—coal mining companies began to suffer dramatic financial collapse (a debt level of 123.9% in 2002). The debt relief provided for these concerns through the restructuring process resulted in medium-term stabilisation, but after 2012 liabilities began to rise once more (reaching a debt level of 74.5% in 2020). Two further periods of losses reduced the value of equity, leading to a situation in which the value of the net assets of the coal mining industry as a whole stood at only PLN 8.5 billion in 2020, i.e., 1/3 of its annual revenues. What is more, since 2003, value transfers to the economic system (a component of GDP) gradually decreased (with significant fluctuations), from 59.1% of the rate of value added to 26.6% in 2020. (Figure 3).

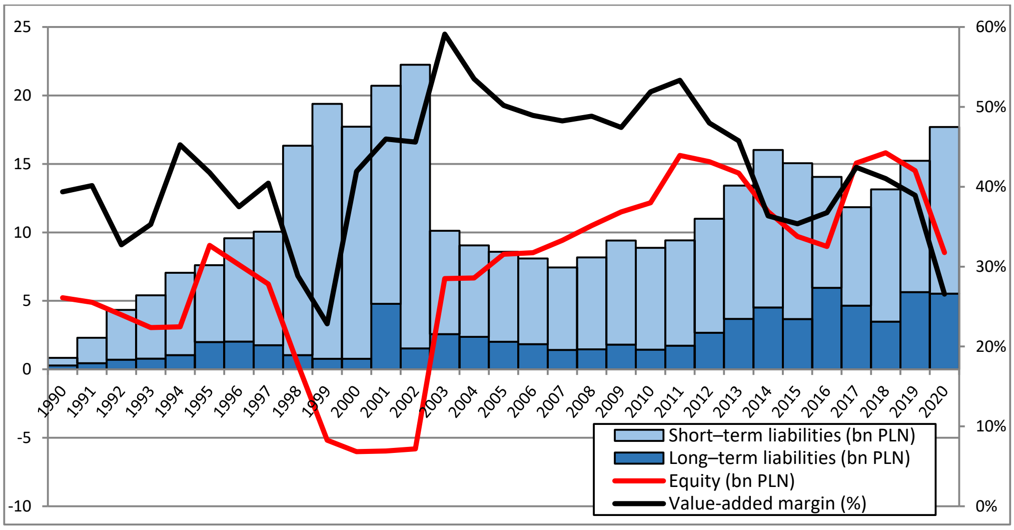


Figure 3. Short and long-term liabilities, equity and value-added margin of coal mining enterprises in 1990–2020. Note: value-added margin—right axis. Source: as in Figure 1.

The asset-capital structure (ACSR) is generally viewed as negative, for at least several reasons. Firstly, in the first four years of restructuring, the ACSR index decreased 7.5-fold, and in the years 1999–2002, it stood at unprecedented, negative levels (negative equity). Secondly, during the years of improvement and relative stabilisation (up until 2012), its average value nevertheless remained extremely low (an average of 0.17 compared to the reference value 1.0). Thirdly, various factors show no indications of any improvement in the asset and capital structure.

This image of a flawed overall structure overlaps with assessments of static and dynamic liquidity and solvency. An almost total correlation can be observed between current and quick liquidity ratios (r = 0.99), close to the level (average value: current liquidity—0.71, quick ratio—0.58) due to the relatively small impact of inventories and above all significantly different *in minus* from the reference values. The correlation between changes in current liquidity and the ACSR ratio was very high (r = 0.81), which is proof of the transfer of defective asset and capital relations from the overall level to the level of working capital management. The operating cash flow and cash flow coverage ratios were negative, which occurred again in 2020. Their level was critically low: PLN 1 of revenues generated on average a financial surplus of PLN 0.03, while PLN 1 covered PLN 0.06 of total liabilities. The solvency ratio based only on the net financial result and depreciation was also very low (on average 0.10), and the correlation with current liquidity was average (r = 0.46). With relatively stable inventory and receivable conversion cycles in terms of their length, the working capital cycle was always negative (due to the length of the short-term liabilities cycle) and reached its peak value of −278 days in 2002, and then, as a result of debt reduction, it was reduced to an average of −63 days.

Efficiency can be measured in terms of profitability and productivity. An assessment of operating profitability in the branch reveals three periods characterised by similar properties: the period up to 2002, when coal mining companies were highly unprofitable concerns; the 2003–2012 period, characterised by positive results with considerable volatility and the 2013–2020 period, when the profitability of these enterprises was shaken twice, and which ended in further major losses. Cost productivity provides support for profitability. Unfortunately, this was not the case with the surveyed companies. Firstly, this was because until 2002 the value of this indicator was lower than 1 (mean value—0.96, minimum—0.84). This situation repeated itself in the years 2019–2020. Secondly, throughout this entire period, an expenditure stream equal to PLN 1 yielded average revenues of just PLN 1.01.

Thirdly, with some fluctuations (a coefficient of variation 9.6%), cost productivity was on a downward path (average annual rate of −1.1%). Asset productivity only grew at any significant rate until 1997, and began to decline after 2003, assuming values below 1 (an average value of 0.81, minimum—0.55). The decline in these values was more pronounced than in the case of cost productivity. The correlation between asset productivity and the operating profitability of assets was slight (r = 0.08), while there was an almost complete correlation between cost productivity and the operating profitability of sales (r = 0.99) (Figure 4).

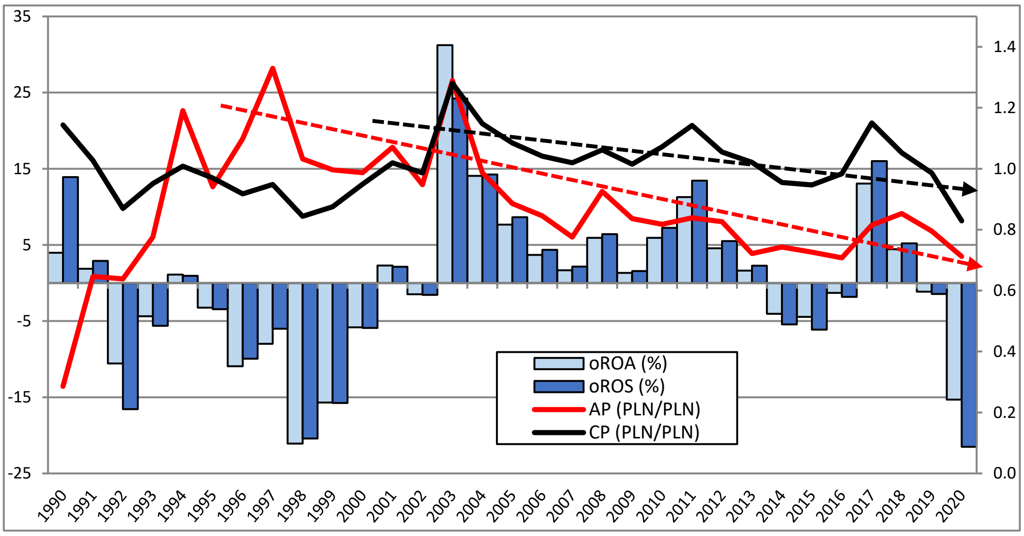


Figure 4. Productivity of assets (AP) and costs (CP), and operating return on assets (oROA) and sales (oROS) of coal mining enterprises in 1990–2020. Note: productivity of assets and costs—right axis. Source: as in Figure 1.

Proof of partial hypothesis H1. The above-mentioned results for the years 1990–2020 provide a legitimate and unquestionable basis for providing a negative verification of the partial hypothesis (H1). In other words, the restructuring of coal mining companies has not achieved its basic goal of sustainable profitability and increasing productivity, including with regards to its main factor, i.e., labour productivity. □

3.3. Assessment of the Structural Changes of Coal Mining Enterprises

Partial hypothesis H2. *Hard coal restructuring has brought about significant changes in the structure of employment, assets, capital expenditure and sales.*

A reduction in underground employment of 75% and a reduction of 85% above ground did not significantly change the employment structure (details in Appendix C) in coal mining companies (NPS = 0.11 compared to 1992). The increase in structural variability observed in 1992–1996 slowed down to a complete stop. The limited volatility of the employment structure is also confirmed by the low volatility of the HHI concentration index (0.459 in 1992 and 0.453 in 2020). The relatively high value of concentration resulted from a significant share of underground workers (63.73% in 1992; 64.37% in 2020). No correlation was observed between the intensity of change in the employment structure and the rate of change in production (r = 0.004), which confirms the lack of any correlation between changes in the employment structure and changes in the volume of production (no cause-and-effect relationship) (Figure 5).

Changes in the volume of hard coal sales varied from year to year, and only in 3 out of the 28 years during this period (1996, 1997, 2004) did actual production exceed the targets. In the remaining years, no mining output and sales targets were set, and, since 2017, sales volume has not been planned at all. The significant decline in sales and mining output was reflected in changes in the sales structure (commercial power engineering, industrial power engineering, industrial and municipal heating plants, other industrial customers, coking plants and other domestic customers). A strong correlation was observed between changes in the sales structure and the sales volume, which was mainly a consequence of the declining share of other domestic recipients, with the exception of the commercial power and heating industries (industry and coking plants). These changes are confirmed in the strong upward trend in the HHI index since 2016. In 2020, the sale of coal to the commercial power industry accounted for as much as 67% of total sales (37% in 1992) (Figure 6).

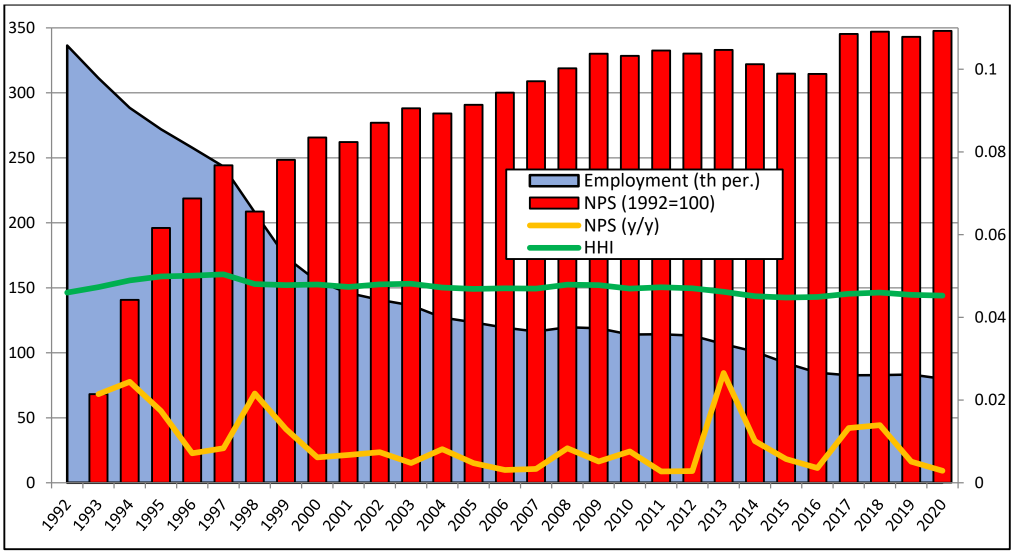


Figure 5. Employment, intensity of structure changes (NPS 1992 = 100%, NPS y/y), concentration (HHI) for coal mining enterprises in 1992–2020. Comments: employment—left axis, HHI—standardised quantity. Comparable data available only since 1992. Source: own study based on data provided by ARP S.A. Katowice. Available online: https://polskirynekwegla.pl/ (accessed on 10 February 2022).

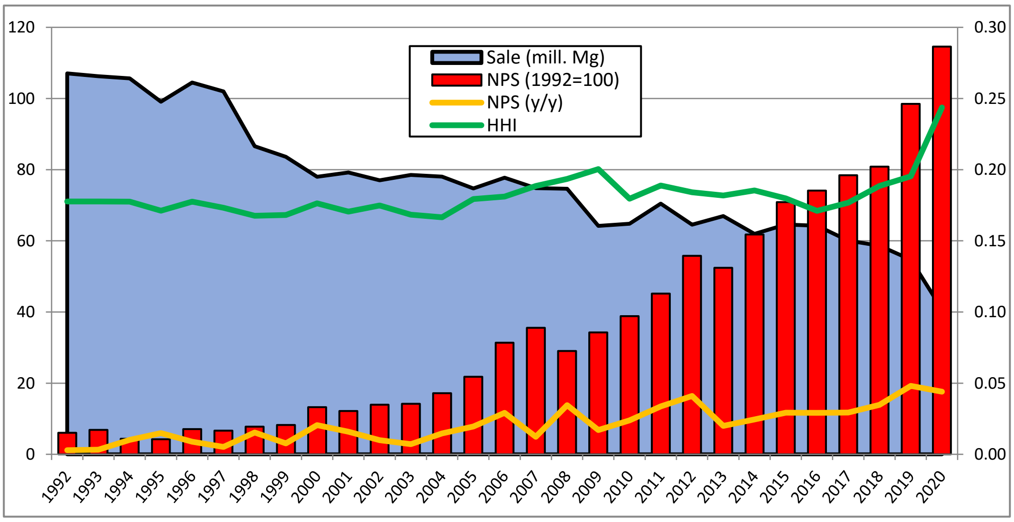


Figure 6. Coal sales, intensity of sales structure transformations ((NPS 1992 = 100%, NPS y/y), concentration (HHI) for coal mining enterprises in 1992–2020. Comments: coal sales—left axis. Other remarks as to Figure 5. Source: as in Figure 5.

The restructuring programs implemented in the years 1993–2007 set specific investment outlay targets to adapt mines to the ongoing technical and technological changes, adjust extracted and mechanically process coal to market needs and reconstruct and modernise machinery and devices. On the other hand, investments in the drilling of mine workings exceeded spending targets for the years 1995–1997 and 2004–2006. Since 2007, neither the size nor the structure of investment outlays has been planned, which was reflected in a greater deconcentration of the structure of investment outlays.

In 1996 and 2004, structural change increased in intensity, which was a consequence of a significant increase in expenditure on the purchase of machinery and equipment. The value of the HHI indicator confirms the high degree of diversification in investment outlays (which covered pits, coal mechanical processing plants, environmental protection, purchases of machinery and equipment and other things) and the lack of any clear direction. The biggest structural change (y/y) occurred in 2004, when there was a sharp reduction in other forms of capital expenditure. Since 2005, the pace and scale of change (annual average NPS = 0.077) in the structure of investment outlays has been waning (Figure 7).

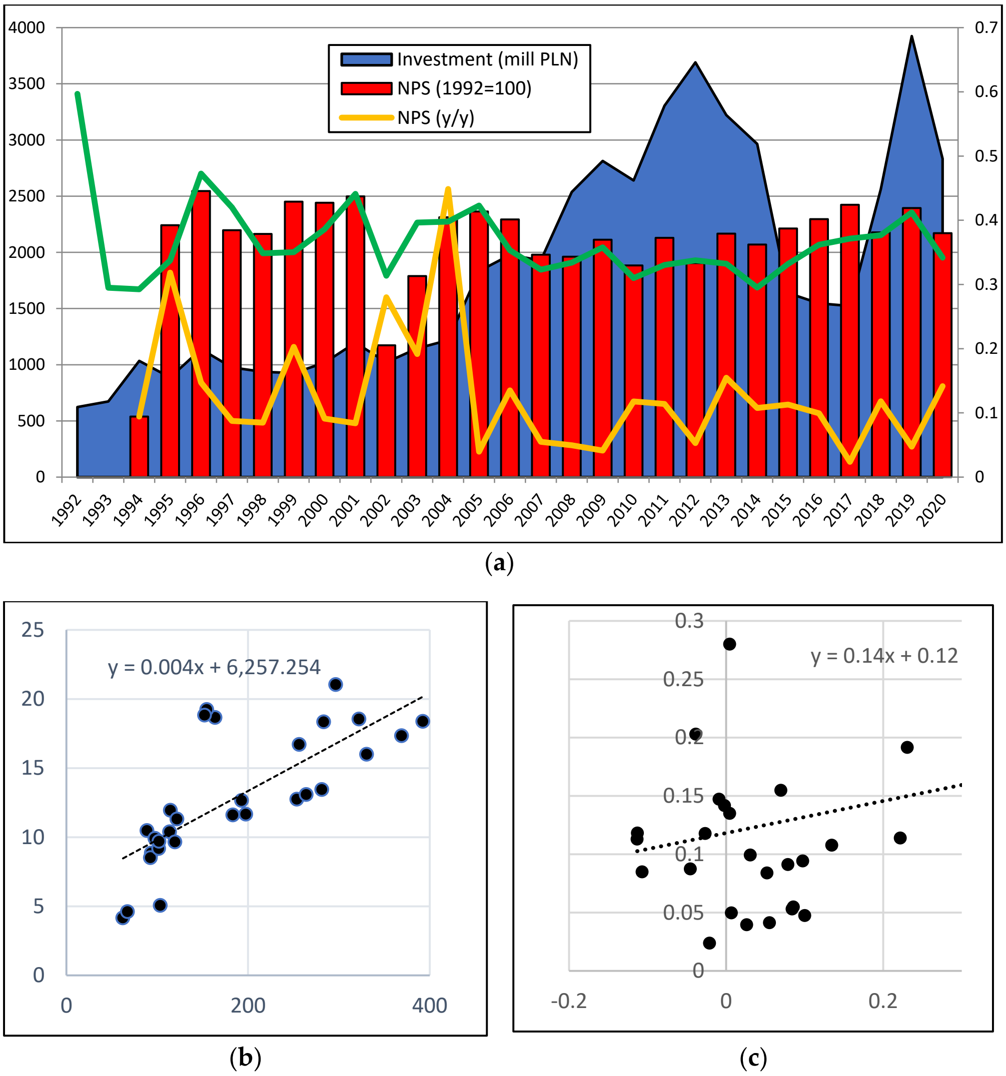
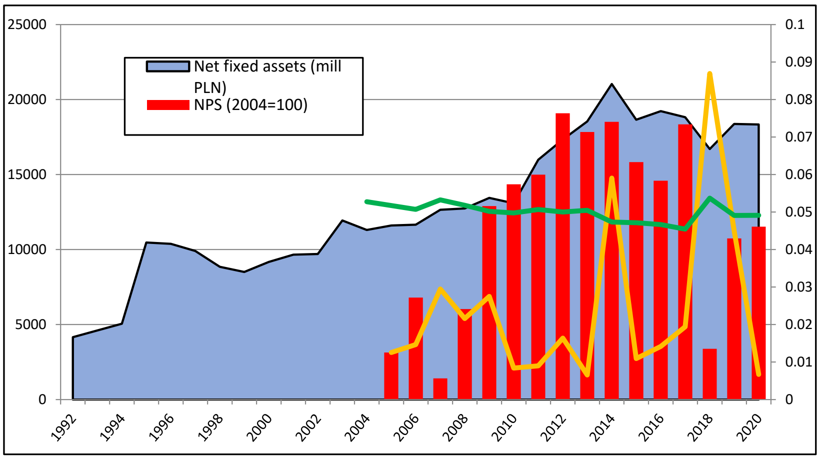


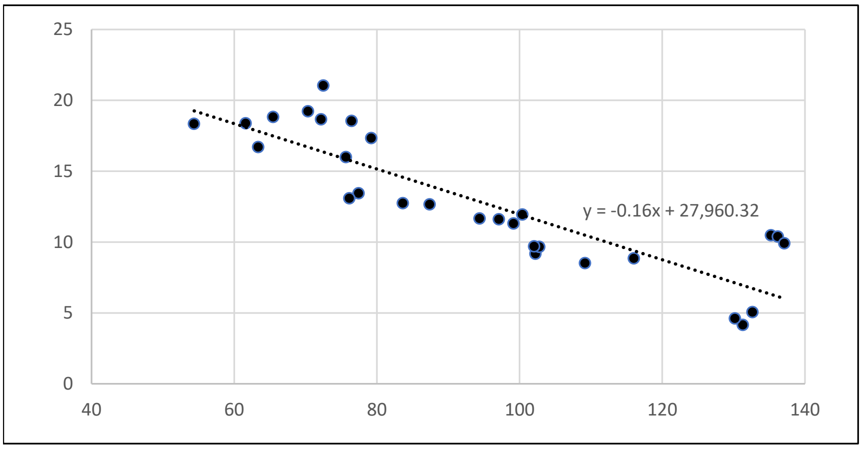
Figure 7. Investment outlays for mining enterprises in Poland in 1992–2020; (**a**) Capital expenditure, intensity of structure changes (NPS 1992 = 100, NPS y/y), and concentration (HHI); (**b**) Regression curve for investment outlays and net fixed assets values; (**c**) Regression curve of the intensity of changes in the structure of investment outlays and the rate of changes in the net fixed assets. Notes: investment outlays—left axis. Remaining remarks as to Figure 5. Source: as in Figure 5.

A weak correlation was observed between the pace and scale of changes in the structure of investment outlays and the value of net fixed assets (r = 0.25). An average correlation existed between the NPS of the investment structure and the rate of change in the value of net fixed assets (r = 0.31), and a slight correlation was noted with the NPS of the structure of assets (r = 0.08), with no regression relationship specified. This indicates that the purpose of the investments was not to further modernise the property structure but rather to continue current operations, and their main focus was the maintenance of mine workings (38% in 2020).

An analysis of the variability of the structure of fixed assets (land, buildings, premises and civil engineering facilities, machinery and technical equipment, means of transport and other fixed assets) reveals slight changes (annual average NPS = 0.018). The high and sustained level of concentration (average HHI = 0.49) was due to a constantly high share of buildings, premises and water engineering facilities (average—63.73%). A very strong negative correlation (r = −0.86) and a satisfactory fit of the regression curve (R^2 = 0.75) for the value of assets and the volume of coal output means that an increase of PLN 1000 PLN in the value of assets resulted in a decrease in output of 0.16 thousand tonnes. A weak correlation (r = 0.24) was observed between the intensity of changes in the structure of assets and the change in the structure of employment. This confirms the lack of any common restructuring policy for these areas. An average correlation with the pace and scale of changes in the asset structure and total productivity (r = 0.41), a weak correlation with productivity per underground worker (r = 0.13) and a weak correlation with the rate of change in productivity (r = 0.14) clearly confirm that the restructuring of fixed assets did not result in any improvement in the operating efficiency of mining enterprises (Figure 8).



(**a**)



(**b**)

Figure 8. Net fixed assets in coal mining companies in Poland in 1992–2020; (**a**) Net fixed assets in 1992–2020, intensity of structure changes (NPS 2004 = 100, NPS y/y), and concentration (HHI) in 2004–2020; (**b**) The regression curve of the net fixed assets and the hard coal output in Poland in 1992–2020. Notes: net fixed assets—left axis. Remaining remarks as to Figure 5. Source: as in Figure 5.

Proof of partial hypothesis H2. The results outlined above provide an unequivocal basis for nullifying the partial hypothesis (H2). This means that the restructuring of hard coal enterprises did not help to achieve the basic goal of rationalising employment. No correlation was observed between changes in the employment structure, the size and rate of coal output and changes in the structure of fixed assets, and mines were not adapted to the technical and technological changes that took place during this period. □

A basic goal of every restructuring program was a reduction in liabilities, first so as to prevent insolvency and liquidation and then to ensure growth. All the programs provided for debt reduction through the implementation of composition and bank settlement proceedings, spreading out and postponing overdue payments or cancelling overdue interest and payments owed to the state. The introduction of special laws regulating the restructuring of hard coal mining debt had the effect of drastically lowering liabilities by over 62% in 2003. Overall, thanks to debt cutting measures based on special provisions introduced in 1998 [142] and 2003 [143], over PLN 18 billion (EUR 3.9 billion) of the debt owed by the hard coal mining industry was written off [144] (see conclusions in Section 3.2).

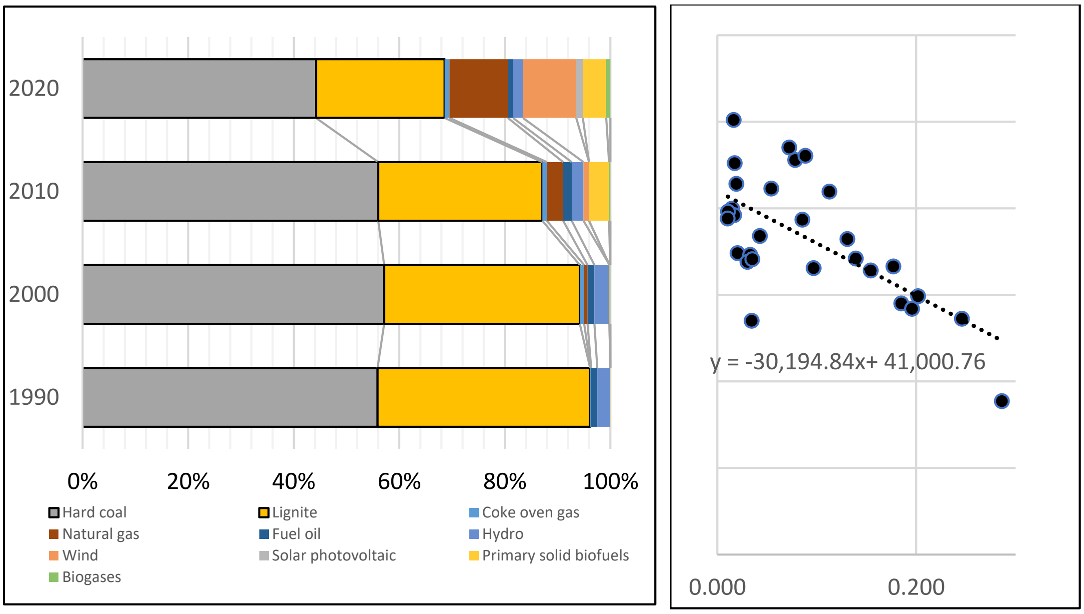
3.4. Assessment of Changes in the Structure of Electricity Generation vs. Hard Coal Mining

Partial hypothesis H3. *The effects of restructuring coal mining companies based on a multidimensional approach are determined by time intervals characterised by elements of homogeneity (time series periodisation).*

Changes introduced in the structure of electricity generation in Poland (hard coal, lignite, natural gas, heating oil, RES) were small in scale (NPS = 0.097, annual average 0.012) up until 2010 (compared to 1990). In the years 2010–2020, the intensity of change in the generation structure was already twice as high (NPS = 0.286 in 2020, 0.032 annually on average) as in the previous 20 years. A very high and negative correlation was observed between changes in the structure of electricity generation (NPS) and (1) sales of steam coal (r = 0.66, unsatisfactory regression fit $R^2 = 0.43$), (2) coal output (r = 0.88, a satisfactory regression fit $R^2 = 0.78$) and (3) the volume of steam coal production (r = 0.91, a good regression fit $R^2 = 0.84$).

The regression relationship outlined above should be interpreted in such a way that a change in the structure of energy production in 1990–2020 by 1% (NPS) resulted in a decrease in thermal coal production by 1.09%, i.e., in a decline in thermal coal production amounting to 2,332,000 tonnes. (Figure 9). This indicates that external factors (i.e., non-mining factors) exerted a significant influence on the volume of coal mined and the nature of changes in its output (mainly with regards to the ways in which increased demand for electricity was covered from sources other than coal.

For the purposes of reinforcing and interpreting the results obtained so far, the authors applied the model system of inequalities [145]. This approach is based on the existence of interdependencies between the dynamics underpinning the main categories that determine the economic condition of an enterprise and its rational (efficient) functioning. Changes in the structure of employment and fixed assets (the resources of enterprises) were first assessed, followed by an evaluation of the changes in the sale and mining of steam coal, total productivity and productivity per underground worker (as effects of operation), as well as the structure of energy production and investments (as external stimulants of changes). A very strong and negative correlation was observed between changes in the structure of the energy mix and sales (SCE) (r = −0.84, a matching regression relationship $R^2 = 0.71$) on the one hand and coal mining (MCE) (r = −0.92, matching the relationship regression $R^2 = 0.84$) on the other. A strong, negative correlation was observed between changes in the structure of electricity generation (EN) and changes in the employment structure (r = −0.70, adjustment of the regression relationship $R^2 = 0.50$) as well as changes in the structure of fixed assets (r = 0.70, adjustment of the regression relationship $R^2 = 0.50$). In the remaining cases, the correlation was weak or slight (Figure 10).



(**a**) (**b**)

Figure 9. Electricity production sources in Poland in 1990–2020; (**a**) The structure of electricity generation in Poland in 1990, 2000, 2010 and 2020; (**b**) The regression curve of the intensity of changes in the structure of electricity generation and the coal production in Poland in 1990–2020 Source: own study based on Eurostat. Available online: https://ec.europa.eu/eurostat/data/database (accessed on 22 February 2022).

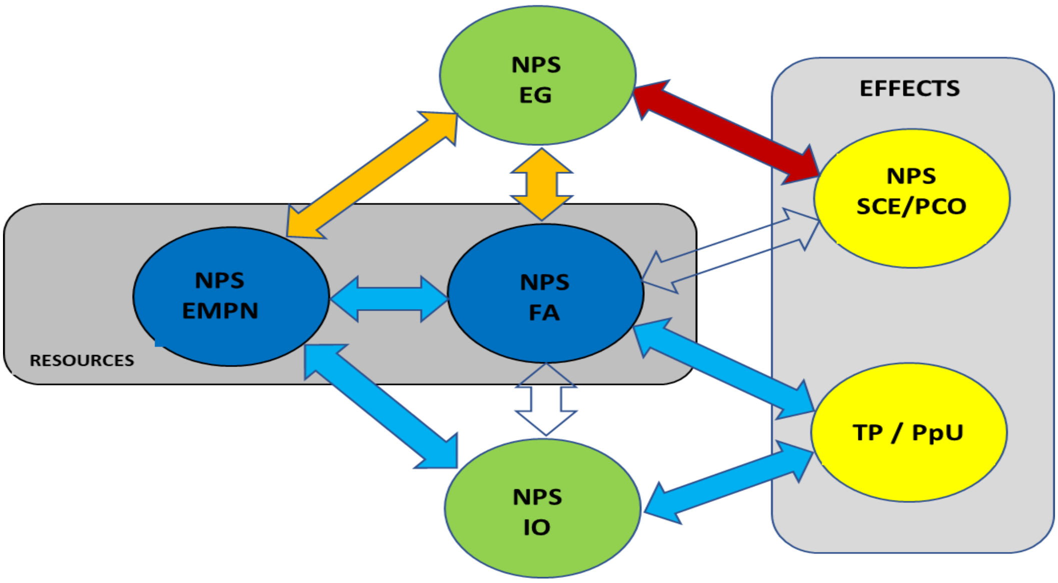


Figure 10. Strength of dependence of selected interdependencies for coal mining enterprises in Poland. Notes: NPS—intensity of structure changes, FA—fixed assets; EMPN—employment, IO—investment outlays; TP—total productivity, PpU—productivity per underground worker; EG—energy generation; PCE—steam coal output; SCE—sale of steam coal. The colour of the arrow indicates the degree of correlation: <0.1 weak (no colour); 0.1–0.3 weak (blue); 0.3–0.5 average (green); 0.5–0.7 high (yellow); 0.7–0.9 very high (orange); >0.9 almost full (red). Source: own study based on data provided by ARP S.A. Katowice branch; own study based on data from hard coal mining restructuring programs in Poland in the years 1993–2020 (Appendix B), materials of the Ministry of Economy. Available online: www.gov.pl (accessed on 2 February 2022), and ARP Katowice. Available online: https://polskirynekwegla.pl/ (accessed on 10 February 2022).

The shape of the steam coal sales curve made it possible to distinguish three distinct periods: (1) 1992–2002 (a decrease in sales with a simultaneous slight change in the structure of electricity generation; annual average NPS = 0.006 and NPS = 0.035 compared to 1992), (2) 2003–2008 (an increase in sales with a simultaneous weak increase in the intensity of changes in the structure of electricity generation, annual average NPS = 0.017 and NPS = 0.073 compared to 1992) and (3) 2009–2020 (a clear downward trend in sales with an equally strong trend towards structural change; annual average NPS = 0.029 and NPS = 0.286 compared to 1992). In addition, sales declined significantly in 2019–2020, which was accompanied by significant changes in the structure of electricity generation compared to 1992 (Figure 11).

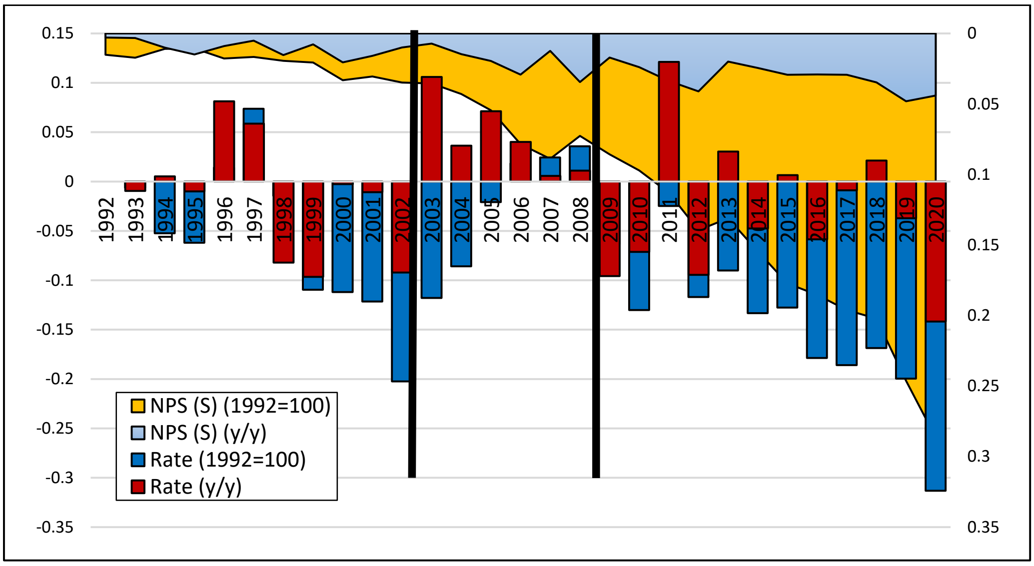


Figure 11. The rate of changes in the sales of steam coal volume, and the variability of changes in the structure of electricity generation in Poland (NPS 1992 = 100, NPS y/y) in 1992–2020. Source: as in Figure 10.

The above results lead to the conclusion that in the years 1992–2020, a strong and negative correlation existed between changes in the structure of electricity generation and steam coal sales volume (r = 0.66), with this structure having a noticeable impact on the sales volume (R^2 = 0.43). An analysis of this relationship in all three of these periods yields the following results:

- 1992–2002—a very strong and negative correlation (r = −0.89, R^2 = 0.79) with production volume and a strong and negative correlation with sales of steam coal (r = −0.67, R^2 = 0.45);
- 2003–2008—a strong and positive correlation with production volume (r = 0.80, R^2 = 0.64) and a very strong and positive correlation with steam coal sales volume (r = 0.93, R^2 = 0.87);
- 2009–2020—a very strong and negative correlation with production volume (r = −0.93, R^2 = 0.88) and a strong and negative correlation with sales of steam coal (r = −0.90, R^2 = 0.81).

Proof of partial hypothesis H3. In conclusion, an assessment of changes in the structure of electricity generation in the years 1992–2020 as well as indicators of changes in hard coal sales for electricity needs (the NPS indicator) confirms partial hypothesis (H3). This means that the restructuring period can be divided into intervals of time with their own homogenous characteristics. □

4. Discussion

When discussing the results of coal mining companies that have undergone continuous restructuring, several factors need to be distinguished [146]. The first is the composition of the determinants of the outcome, especially in operational terms, and concerns not only absolute differences in revenues and costs but also their dynamics and the cost structure [147,148]. The labour factor exerted considerable pressure on costs during times of economic prosperity, which made it impossible to limit such expenditure in periods of falling prices, which in turn led to poorer results and higher losses [149]. Another problem was that operating costs were burdened with capital expenditure; faced with problems of low creditworthiness, enterprises made use of a widening result field and increased their costs through investments, which also could not be quickly brought under control during times of recession.

In the years 1990–2020, productivity suffered a linear and substantial decline [150] with the rapidly shrinking workforce (with a positive or negative deviation from production dynamics) [151]. The costs connected with cutting employment constituted the main component of cost-cutting measures in mining in general [152]. Labour productivity, measured in terms of revenues, increased overall, but from the point of view of efficiency, this indicator turns out to be misleading, as it is based on a quantitative reduction in the volume of production and labour [153]. After 2003, total cost productivity began to decline, and asset productivity at an even faster pace. In these circumstances, the next recessions (2014–2016 and the even sharper downturn of 2019–2020) were inevitable, and they were triggered by a slight correction in coal prices.

Low productivity and operational efficiency are quickly and quite strongly reflected in levels of solvency and liquidity as well as in working capital cycles [154]. Debt increases rapidly, and an enterprise's ability to pay its liabilities decreases. In these conditions, enterprises are no longer capable of self-financing and expect public assistance in the form of subventions and government subsidies [155]. Plans to shift away from direct government-initiated restructuring after 2006 remained a fact for only a few years and became utter fiction after 2013 [156]. To keep coal mining companies operating in order to supply power plants with raw material, further large subsidies were needed [157].

Using the logit model for predicting the degree of financial risk for a going concern (FTD), a synthesis was constructed of partial assessments of the results of coal mining enterprises. This model is a multidimensional tool for assessing the financial situation of an enterprise, as was previously mentioned, and functions as a kind of barometer of this financial condition [158]. The results of the findings are, firstly, that the level of risk for coal mining companies significantly exceeds the results of all industrial enterprises (including those involved in the mining of other natural resources). On average, this indicator was 1.8 times higher than for industry as a whole. Secondly, this is a highly volatile measure (volatility coefficient of 63.7%), which is particularly evident when considering the stabilisation of the industry observed since 2009. Thirdly, the course of the FTD curve makes it possible to distinguish three characteristic periods in the course and effects of restructuring in the coal mining industry: (1) 1990–2002 (achieving financial independence and profitability), (2) 2003–2013 (relative stabilisation and departure from direct restructuring measures), (3) 2014–2020 (a return to conditions of crisis). Particularly visible are the effects of the debt reduction (measures implemented in 2002–2003) and the return of crisis (2019–2020) (Figure 12).

In conclusion, the results of restructuring coal mining companies in 1990–2020 assessed by means of the multi-component FTD measure is further evidence in favour of adopting partial hypothesis (H3). This means that it is possible to periodise the tested time series, which was reinforced by the previously demonstrated occurrence of close (convergent) time intervals distinguished according to the intensity of changes in the structure of electricity generation in connection with changes in hard coal output for energy purposes (see Section 3.4).

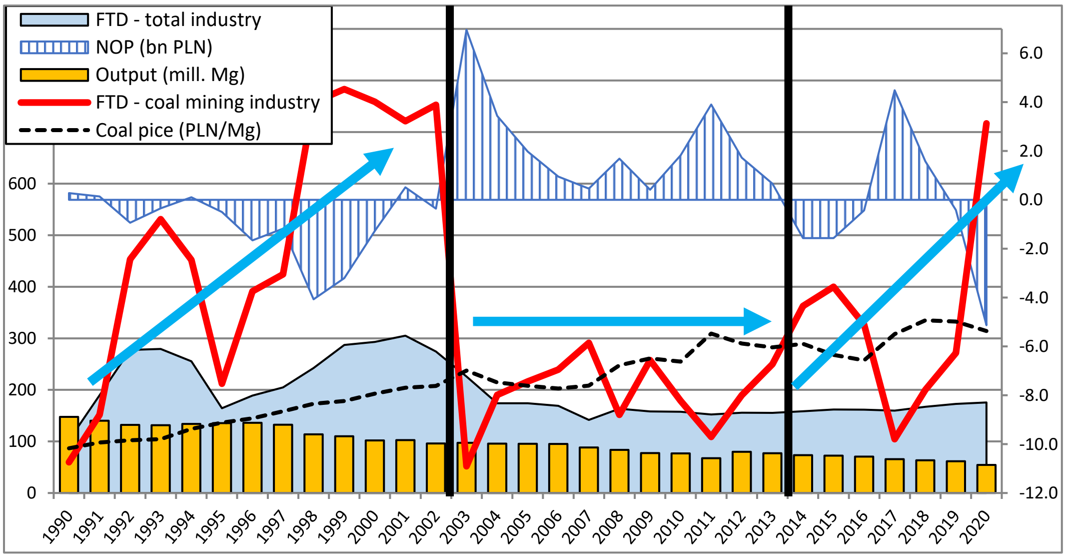


Figure 12. Financial threat degree of going concern (FTD) against key economic criteria for coal mining enterprises in 1990–2020. Note: net operating profit (NOP)—right axis. Source: as in Figure 1.

No restructuring can be a stand-alone undertaking [159], especially when it concerns an entire economic sector. The key tasks of restructuring in the case of the hard coal mining industry were to achieve profitability, modernise mining technology, increase productivity and efficiency and promote efficient management practices [160]. Unfortunately, the long-term effects of these measures have been negative. Moreover, the future situation will be conditioned by the interplay of a number of factors, which will give rise to two opposing relationships:

- the current state of hard coal resources will, with rational management (without embarking on the exploitation of new deposits), ensure its supply up to 2049 [161],
- the current difficult financial state of the mining industry poses a serious barrier to, if not makes impossible, the implementation of the necessary development investments that would ensure an adequate supply of raw materials in the future [162].

A more detailed discussion of the effects of the restructuring programmes launched in the branch after 1990, led to the following conclusions:

1. The restructuring activities carried out during this period did not bring the expected results, as is evidenced by the poor condition of mining enterprises [163].
2. None of the 1992–1997 programs were fully successful, and most did not live up to the hopes placed in them [164,165] because of the inconsistent implementation of restructuring programs. Makieła [166] tried to prove it earlier but limited his research only to the analysis of the magnitude differentiation of only three measures, without attempting a comprehensive evaluation.
3. Organisational changes in mining enterprises were not always accompanied by planned job cuts [167]. Gumiński [168] previously tried to confirm this conclusion in research on the effective use of human resources, but he limited himself only to research and evaluation of selected measures.
4. The main methods used to reduce employment were natural redundancy, restrictions on admissions and, to a small extent, retirement incentives (early retirement, retraining courses, relocations, etc.), which was also noted in the research conducted by Bluszcz [169], which pointed out the lack of employment alternatives elsewhere.
5. The absence of major changes in employment structures and fixed assets indicates a lack of any decisive policy or ongoing modernisation of these structures. Earlier, Gumiński [170] and Grzybek [171] tried to assess it, but they did not use any statistical evaluation analysis tools with features of coherence.

6. A strong and negative correlation was observed between changes in the form and structure of fixed assets and the volume of mining output, with no improvement in the operating efficiency of mining enterprises. The lack of any correlation between the structure of assets and productivity and employment structure clearly indicates that the restructuring measures implemented during this period had no economic effect.
7. The failure to achieve the desired changes was a consequence of exogenous processes, namely the task of creating legal and environmental regulations as well as the fact that political pressures did not take into account the economic conditions in which mining enterprises functioned [39].
8. Since 2007, the authorities have abandoned the idea of setting coal output and sales targets due to their inconsistency with market trends and the objectives of energy policy [172]. No effective measures were taken in a timely manner to adjust mining enterprises to the changing market situation, which was also confirmed in the studies conducted by Turek & Jelonek-Kowalska [173]. This was due to a number of factors, including geopolitical [174], economic [175] and social [176] factors.
9. The cut-back in mining operations and coal output came as a result of the need to abruptly adapt to the declining need for coal, which was only to a small extent caused by the energy transition, and shrinking demand for steam coal. Gumiński, Karbownik and Włodarski [91] came to a similar conclusion, but they did not take into account the analysis of interdependencies carried out in this article.
10. Although, as was shown in the research, an important element of the above restructuring programs was ensuring the country's energy security, especially given the insufficient capacity provided by alternative energy sources [177–179], this security has not been adequately guaranteed. This was pointed out by Kaliski et al. [180] in their research, but they did not attempt to indicate the direction of policy changes, which in the current situation is of key importance for Poland.

Proof of main hypothesis. The research findings presented so far, including the verification of sub-hypotheses H1–H3 and their initial discussion, have denied the validity of the main hypothesis. This means that the restructuring of hard coal enterprises, being neither effective nor efficient, failed to accelerate changes in the energy mix. □

A number of studies on mining conducted so far have concerned only the analysis, and in part the evaluation, of the changes that have taken place in the context of a single programme being implemented, or have concerned a limited scope, number and type of measures. The most extensive research on changes in mining was conducted by Makieła [166], Turek and Jonek-Kowalska [173]. They focused only on selected, isolated areas, without trying to build a comprehensive assessment. This deficit was filled by the research in the article through the use of a logit model, which allowed, in synthetic terms, a comprehensive, objective and multidimensional assessment of financial health and risk in the long term. This assessment showed that the restructuring of coal mining companies failed to achieve the primary objective of sustainable profitability and productivity growth. A multidimensional diagnosis of the employment structure and the assessment of differences between individual plants in the hard coal mining industry, carried out by Frankowski et al. [176], included only a detailed analysis of the area of employment and its structure. This article strengthens the method of evaluating the changes in the structure of employment using the taxonomy of structures and evaluating the interdependence with other resources of the enterprises, showing negligible changes in the structure of employment, assets, capital expenditures and sales. Gumiński [168], in his research, focused on studies on selected objects of analysis (questionnaire surveys), which as a result prevented the identification of endogenous and exogenous factors affecting the changes that occurred. This missing area was filled in the article using taxonomic analysis, which was supported by regression analysis. A definite weakness of previous studies is the short time horizon, which covered only short periods, mostly limited to specific restructuring programmes, and the low cross-sectionality of the analysis. The long-term studies conducted allowed the determination of the time intervals with the features of homogeneity (periodisation of the time series). The added value of the research in the article is the analysis of the full restructuring period and all restructuring programmes, as well as the wide range of measures analysed. This article reinforces the assessment by conducting research that provides clear findings in this regard, which were verified using objective assessment tools. As in the past, the authors have referred in their research mainly to the analyses concerning the development of the renewable energy market [181–183], technologies related to the production of energy from RES [184], the socio-environmental effects of energy use and the importance of the conditions related to the limits of pollutant emissions [185], accepting (postulatively) the direction of decarbonisation in energy production [186] and departing from the issue of the necessary coherence of restructuring changes in the mining and power industries. This relationship was demonstrated in the conducted research by confirming the high correlation between changes in the energy mix and changes in the structures characterising mining companies. The results of the research described in the article indicate a very important issue. In order to accelerate the change in the energy mix, the restructuring of the coal mining industry should support the restructuring of the energy sector.

If we consider the last of the above conclusions in a broader context, it was thought [68] that energy security (as defined in 1990) required meeting three conditions simultaneously: ensuring security of the energy supply, maintaining socially justified energy prices and minimising environmental damage. To guarantee energy security understood in this way, it was necessary, inter alia, to ensure (as was confirmed in the goals of subsequent energy policies (PEP)) the possibility of satisfying demand for coal from domestic sources. This was to be achieved by measures aimed at modernising technologies connected with mining and preparing coal for electricity purposes, as well as by creating incentive mechanisms encouraging the maintenance and development of suitable production capacities [72] (p. 10). Unfortunately, the results of the present analysis show that underinvestment in the modernisation of production assets and the exploitation of new deposits places in doubt the ability of the country to meet its needs for coal up until 2049. The situation is serious even despite the predicted gradual decline in demand for coal for electricity generation purposes (set to decline by over 40% in 2040 compared to 2020), according to the forecasts presented in PEP 2040 [49].

On the other hand, the ongoing energy transition in Europe, which is taking place in an expanding common European energy market (Regulation 2019/943/EU) [187], poses another threat to Poland's energy security. Delays in the simultaneous reform of the power engineering and coal mining sectors, as well as prolonging the use of coal as the country's basic fuel while other EU countries are rapidly developing renewable energy sources, may result in the displacement of domestic energy from the power system due to the "merit order" effect [188–190]. This means that priority in the energy system is given to energy with the lowest variable cost of production. In a common energy market where neighbouring countries engage in large scale production from renewable sources, imported energy will be the first to be accepted into the Polish energy system. Renewable energy is characterised by negligible variable costs (it does not use fuel and does not require manpower). This will put the conventional energy sector in a difficult economic situation.

Much will also depend on the pace of development of the Polish RES sector. The key question seems to be whether Poland will maintain the relatively high pace of RES development, already presented in the article. The government's forecasts included in the Energy Policy of Poland by 2040 [49] assume an increase in electricity production from RES by only 13% during the current decade (until 2030). This should increase the share of renewable energy sources in electricity production to 32%. Growth is expected to occur—at different rates—in all renewable sources, as evidenced by official [49] and independent studies [191,192]. However, the development of RES is highly dependent on legal solutions and may be quickly stopped or accelerated [191,193] depending on the political will of the government.

Returning to the conventional energy sector, on the basis of the aforementioned regulations regarding the internal energy market, in 2025 EU member states will no longer be able to support producers of coal-generated electricity via, for example, a system of capacity payments, which currently constitutes an important source of financing for conventional power plants [194,195]. Indirectly, this will have a significant impact on mining through a wave-like reduction in demand for coal—along with the exclusion of subsequent power plants from the system. The financial condition of coal mining companies will deteriorate further, and they will be cut off from funds needed for investments. As a result, the Polish economy will become dependent on energy imports, despite theoretically having significant domestic energy resources at its disposal. This is another argument in favour of not slowing down the pace of energy transition, despite the problems caused by the war in Ukraine and subsequent increases in gas prices, which are treated as a transition fuel for a target zero-emission economy. In conclusion, it can be argued that by lagging behind in the energy transition process, Poland faces a significant threat to its energy security in the medium term.

Every research project has certain limitations. These can be mitigated by ensuring the coherence and consistency of the research framework, as well as by using advanced research methods and databases and applying multiple arguments and long-term timeframes. In the present research, above all else, there were no problems regarding the representativeness of the study (the study population comprised all enterprises in the sector). One limitation was the lack of data availability to conduct structure taxonomy and regression analyses for all measures and the full period (31 years). An additional limitation was the heterogeneity, large cross-sectional variation and discrepancies in the secondary data sets, the mitigation of which was attempted by accessing the primary data. In addition, the depth structural and ownership changes (liquidations, mergers of mines and mining companies) made it difficult to maintain comparability of analysis. The abandonment since 2007 of quantitative target setting in restructuring programmes has weakened the clear assessment of the effects achieved. In part, this problem was solved in the study by using taxonomic analysis to determine the intensity of changes occurring and objective comparisons. As a consequence, generalising conclusions can be drawn with a high level of reliability. This also applies to the trends and dependencies observed in the research due to its very long and exhaustive time horizon (31 years). Methodological limitations were overcome by applying multi-sectional sub-measures, a multi-dimensional logistic regression measure and taxonomic measures of structure variability. Of course, other methods may produce different results, but it can be argued that the general trends, relationships and structures would not be significantly different. Furthermore, there is no limitation on the degree of applicability of the research. It is intended as a universal diagnostic tool. Both the methods used and the research framework enable its use in a broad, international application. This represents the value of universality of the research and comparability of the results obtained, which has not been achieved so far.

The conclusion that the restructuring of hard coal enterprises, being neither effective nor efficient, did not accelerate changes in the energy mix, provides the platform for further research. The latter will focus on the task of identifying and measuring the factors that influenced the dynamic though still insufficient development of non-coal energy sources, in particular renewable energy sources. Specifically, this research will address:

- an assessment of the effectiveness of the use of lignite for power generation to date and the prospects for maintaining it,
- identification of determinants and barriers for the development of renewable energy sources,
- an assessment of the economically justifiable life of coal-fired power and heat generation sources given the need for energy security,
- evaluation of the limits of the efficiency (upgrades and creation of new ones) of energy generation sources as a relation of effects and expenditures (with the considered use of non-parametric methods: DEA or FDH),

- selection of energy generation sources for the mix as a relativisation of their efficiency to the energy security factor.

The present research, which has the character of a diagnosis of the state of dependence of the effects of coal mining restructuring and changes in the power industry, as indicated, is the first stage of a widely conducted study. The next step will involve a comparative analysis of the efficiency boundaries (the relationship between effects and expenditures) of all generation sources. Combining the current diagnosis with such an efficiency analysis (non-parametric approach) will allow the formulation of the main building blocks for a new energy transition policy. Already now, however, after the first stage of the diagnosis concerning hard coal mining, the main pillars (directions) of this policy can be formulated:

- removal of regulatory barriers to the development of wind and solar power generation (e.g., reduction of the minimum distance of windmills from buildings, return to net metering, not just net billing);
- government investments into the expansion and upgrade of electricity grid infrastructure, which is a bottleneck for RES development;
- acceleration of design work and investment contracts for the construction of a nuclear power plant, which is a stable source of energy demand coverage in the face of the significant amplitude of fluctuations inherent in RES;
- upgrading of coal-powered generating units in large power plants using new, already available technologies that reduce the burden on the environment and the amount of emission fees;
- use of accumulated funds from the sale of the EU ETS and their increase using government subsidies for the purpose of accelerating the development of RES and "leapfrogging" the hitherto planned natural gas phase;
- setting new targets and activities in the field of the restructuring of hard coal and lignite mining resulting from (following) the developed new energy policy (increase in efficiency, new technologies, intensification of structural reconstruction), based on the optimisation of the energy mix and the context of energy security.

The results of the research conducted so far, the diagnosis made on their basis and the above-mentioned pillars of the future energy policy prove that the pace of Poland's energy transition should be accelerated. The prospect of abandoning coal by 2049 is too distant, not only because of environmental factors, but also in view of the country's energy security. In the conditions of the single EU energy market, the merit order effect is in force, and, at the same time, given that state support for the capacity market is now prohibited and prices of emission allowances are above EUR 60, conventional energy may be forced out of the market, and the ability to generate revenues sufficient to cover operating costs will be lost.

5. Conclusions

The research results presented and discussed in the present article yield several general conclusions. First, coal mining companies have not achieved sustainable profitability and competitiveness on the open coal market. Secondly, restructuring has not brought about any significant structural changes in any of the basic economic categories: employment, assets, capital expenditure and sales. Third, no significant technical and technological progress has been achieved.

The main dependency shown in the article is that a 1 pp. change in the structure of electricity generation resulted in a 2.04 pp reduction in coal output and a 1.09 pp decrease in sales of steam coal. When assessing this dependency, it should be borne in mind that coal output, especially in terms of its consumption for energy purposes, only declined by a few percent in the years 1990–2020. This means that the changes in the energy mix were only possible by covering higher energy demand by increasing the use of non-coal energy sources (8.5 times, including 15 times RES). What is more, the share of these sources only began to increase rapidly (exponentially) at the beginning of the 21st century (gas), and later only in the case of energy from renewable sources (wind farms), and from photovoltaics the most, but only after 2011.

The linear decline in hard coal production as well as the exponential share of renewable energy sources in the total energy mix further highlights the argument presented in the detailed conclusions, namely that the restructuring of hard coal enterprises, being neither effective nor efficient, failed to accelerate changes in the energy mix. In particular, this means that there was no consistency (follow-up) between the forms and effects of restructuring applied to coal mining companies in Poland and modifications in the country's energy mix in response to the energy transition.

The negative assessment of restructuring presented above is reinforced by the fact that in 1990–2020, very significant sums to the amount of EUR 57.3 billion (9.3% of GDP in 2020) were set aside in the budget for subventions, subsidies and other encumbrances for the sector. Moreover, the cost of maintaining the hard coal mining industry until 2049 will require an additional approximately EUR 69.7 billion (11.3% of GDP in 2020). Such expenditure, both incurred already and still planned, should be considered wasted in the sense that it failed to accelerate the dynamics of the energy transition.

Author Contributions: Conceptualization, J.K., K.K. and W.S.; methodology, J.K. and K.K.; validation, W.S.; investigation, J.K., K.K. and W.S.; resources, J.K., K.K. and W.S.; data curation, J.K., K.K. and W.S.; writing—original draft preparation, J.K. (transition and restructuring; productivity and effectiveness; financial and threat prediction analysis), K.K. (coal mining restructuring in Europe and polish government restructuring programs; structure and concentration analysis) and W.S. (energy transition in EU, energy mix sources, polish energy policy); writing—review and editing, J.K., K.K. and W.S.; visualization, J.K. and K.K.; supervision, J.K. Authorship is limited only to those who have contributed substantially to the research and article. All authors have read and agreed to the published version of the manuscript.

Funding: This research and publication was funded by a subvention granted to the Cracow University of Economics.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Restrictions apply to the availability of these data. Data were obtained from: GUS Warszawa (Statistical Head Office in Warsaw)—databases are of limited access and are available (Statistics Poland Databases; available online: https://stat.gov.pl/en/databases/ accessed on 4 February 2022) for a fee and with the permission of GUS, Warsaw; Pont Info Warsaw (Poland), Gospodarka SŚDP—commercial databases are available (Gospodarka SŚDP; available online: http://baza.pontinfo.com.pl/index.php accessed on 2 February 2022) for a fee and with the permission of Pont Info, Warsaw; EUROSTAT—unlimited public access databases (available online: https://ec.europa.eu/eurostat/data/database accessed on 22 February 2022); Agencja Rozwoju Przemysłu (ARP—Industrial Development Agency)—commercial databases are available (available online: https://polskirynekwegla.pl/ accessed on 10 February 2022) for a fee and with the permission of ARP.

Conflicts of Interest: The authors declare no conflict of interest. The funder had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A

The financial standing and restructuring effect evaluation measures for coal mining enterprises:

- resources: fixed and total assets, accumulated depreciation, inventories, receivables, short-term liabilities, number of employees, net working capital,
- flows: revenues from sales, operating and total costs, net operating and financial results, investment expenditures, depreciation, export sales,
- rates of use:

- general financial standing: ACSR asset-capital structure ratio,
- debt: STDR—short-term debt ratio, TDR—total debt ratio,
- static liquidity and solvency: CLR—current liquidity ratio, QLR—quick liquidity ratio, SR—solvency ratio,
- dynamic liquidity: SCER—sales cash efficiency ratio, CFCR—cash flow coverage ratio,
- working capital management: IC—inventories cycle, RC—receivables cycle, STLC—short-term liabilities cycle, NWCC—net working capital cycle,
- profitability: oROS—operating return on sales, oROA—operating return on assets, ROE—return on equity, VAM—value-added margin,

- efficiency and effectiveness: LE—labour effectiveness, LP—labor productivity, AP—assets productivity, CP—cost productivity, AR—fixed asset renewal.

The intensity of structural changes standing and restructuring effect evaluation measures for coal mining enterprises:

- resources: fixed assets, employment, hard coal production,
- flows: hard coal sales, investment outlays, electricity generation.
- rates of use:
  - fixed assets FA,
  - employment EMPN,
  - investment outlays IO,
  - total productivity TP,
  - productivity per underground worker PpU,
  - energy generation EG,
  - power coal mining PCM,
  - sale of energy coal SCE.

Appendix B

Hard coal restructuring programs:

1. Program I—*Restrukturyzacja górnictwa węgla kamiennego w Polsce (Hard coal mining restructuring in Poland)—the implementation of the first stage in 1993, within the financial capacity of the state)—realizacja pierwszego etapu w 1993 roku w ramach możliwości finansowych państwa* (przyjęty przez Radę Ministrów w dniu 15 marca 1993 roku.
2. Program II—*Program powstrzymania upadłości górnictwa węgla kamiennego w Polsce (The program to stop the bankruptcy of hard coal mining in Poland) (realizacja w okresie 15.07–31.12.1993 roku)* przekazany Komitetowi Ekonomicznemu Rady Ministrów w dniu 2 sierpnia 1993 roku.
3. Program III—*Restrukturyzacja górnictwa węgla kamiennego. Część II. Program dla realizacji II etapu w okresie 1994–1995 roku (Hard coal mining restructuring. Part II. Program for the implementation of the 2nd stage in the period 1994–1995)* zaakceptowany przez Komitet Ekonomiczny Rady Ministrów w dniu 18 lutego 1994 roku.
4. Program IV—*Górnictwo węgla kamiennego, polityka państwa i sektora na lata 1996–2000. Program dostosowania górnictwa węgla kamiennego do warunków gospodarki rynkowej i międzynarodowej konkurencji (Hard coal mining, state and sector policy for 1996–2000. Program of adjusting the hard coal mining to the conditions of the market economy and international competition)* przyjęty przez Radę Ministrów w dniu 30 kwietnia 1996 roku.
5. Program V—*Reforma górnictwa węgla kamiennego w Polsce w latach 1998–2002 (The reform of hard coal mining in Poland in 1998–2002)* przyjęta przez Radę Ministrów w dniu 30 czerwca 1998 roku wraz z Korektę rządowego programu *Reforma górnictwa węgla kamiennego w Polsce w latach 1998–2002 (The reform of hard coal mining in Poland in 1998–2002)* przyjęta przez Radę Ministrów w dniu 21 grudnia 1999 roku.
6. Program VI—*Program restrukturyzacji górnictwa węgla kamiennego w Polsce w latach 2003*–2006 *z* wykorzystaniem ustaw antykryzysowych i zainicjowaniem prywatyzacji niektórych kopalń *(Hard coal mining restructuring program in Poland in the years*

2003–2006 with the use of anti-crisis acts and initiation of privatization of some mines) przyjęty przez Radę Ministrów w dniu 20 listopada 2002 roku (z korektami wynikającymi z Porozumienia strony rządowej ze stroną związkową z dnia 11 grudnia 2002 roku oraz korektami wynikającymi ze stanu prawnego sektora na dzień 10 stycznia 2003 roku), przyjęty przez Radę Ministrów w dniu 28 stycznia 2003 roku.

7. Program VII—*Restrukturyzacja górnictwa węgla kamiennego w latach 2004–2006 oraz strategia na lata 2007–2010 (Hard coal mining restructuring in 2004–2006 and the strategy for 2007–2010)* przyjęta przez Radę Ministrów w dniu 27 kwietnia 2004 roku.
8. Program VIII—*Strategia działalności górnictwa węgla kamiennego w Polsce w latach 2007*–2015 *(Strategy of hard coal mining activity in Poland in the years 2007–2015)* przyjęta przez Radę Ministrów w dniu 31 lipca 2007 roku wraz z Korektą programu rządowego przyjętą przez Radę Ministrów w dniu 24 lipca 2009 roku.
9. Program IX—*Program dla sektora górnictwa węgla kamiennego w Polsce do 2030 roku (Program for the hard coal mining sector in Poland until 2030)* przyjęty przez Radę Ministrów w dniu 23 stycznia 2018 roku.

Appendix C

Table A1. Intensity of changes in the structure of employment (NPS) in mining enterprises in Poland in 1992–2020.

1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
0.000	0.021	0.044	0.062	0.069	0.077	0.066	0.078	0.084	0.082	0.087	0.091	0.089	0.091	0.094	0.097	0.100	0.104	0.103	0.105	0.104	0.105	0.101	0.099	0.099	0.109	0.109	0.108	0.109
0.021	0.000	0.024	0.041	0.048	0.056	0.046	0.058	0.064	0.063	0.067	0.071	0.070	0.072	0.075	0.077	0.081	0.084	0.084	0.085	0.084	0.087	0.093	0.095	0.093	0.095	0.093	0.097	0.100
0.044	0.024	0.000	0.017	0.024	0.033	0.027	0.040	0.044	0.048	0.048	0.050	0.057	0.061	0.063	0.066	0.061	0.065	0.072	0.070	0.072	0.080	0.086	0.087	0.086	0.088	0.086	0.090	0.092
0.062	0.041	0.017	0.000	0.007	0.015	0.021	0.034	0.038	0.043	0.042	0.044	0.051	0.056	0.057	0.060	0.055	0.059	0.066	0.064	0.066	0.072	0.080	0.082	0.080	0.081	0.080	0.084	0.087
0.069	0.048	0.024	0.007	0.000	0.008	0.020	0.029	0.033	0.038	0.037	0.039	0.046	0.051	0.052	0.055	0.050	0.054	0.061	0.059	0.061	0.067	0.075	0.076	0.075	0.076	0.075	0.079	0.082
0.077	0.056	0.033	0.015	0.008	0.000	0.022	0.024	0.028	0.033	0.032	0.034	0.041	0.046	0.047	0.050	0.045	0.049	0.056	0.054	0.056	0.063	0.070	0.072	0.070	0.071	0.070	0.074	0.077
0.066	0.046	0.027	0.021	0.020	0.022	0.000	0.013	0.018	0.021	0.021	0.025	0.030	0.034	0.036	0.039	0.035	0.039	0.045	0.043	0.045	0.054	0.060	0.061	0.059	0.062	0.059	0.063	0.065
0.078	0.058	0.040	0.034	0.029	0.024	0.013	0.000	0.006	0.008	0.011	0.016	0.019	0.024	0.025	0.028	0.025	0.030	0.034	0.033	0.033	0.045	0.051	0.052	0.048	0.053	0.046	0.050	0.052
0.084	0.064	0.044	0.038	0.033	0.028	0.018	0.006	0.000	0.007	0.005	0.009	0.014	0.019	0.020	0.023	0.019	0.024	0.029	0.029	0.029	0.043	0.049	0.050	0.047	0.051	0.045	0.048	0.049
0.082	0.063	0.048	0.043	0.038	0.033	0.021	0.008	0.007	0.000	0.007	0.011	0.011	0.015	0.017	0.019	0.021	0.026	0.025	0.025	0.025	0.041	0.047	0.048	0.045	0.049	0.043	0.046	0.047
0.087	0.067	0.048	0.042	0.037	0.032	0.021	0.011	0.005	0.007	0.000	0.005	0.009	0.014	0.015	0.018	0.014	0.019	0.024	0.024	0.024	0.041	0.047	0.048	0.044	0.049	0.042	0.045	0.047
0.091	0.071	0.050	0.044	0.039	0.034	0.025	0.016	0.009	0.011	0.005	0.000	0.008	0.012	0.013	0.016	0.011	0.016	0.022	0.020	0.022	0.041	0.047	0.048	0.045	0.049	0.042	0.046	0.047
0.089	0.070	0.057	0.051	0.046	0.041	0.030	0.019	0.014	0.011	0.009	0.008	0.000	0.005	0.006	0.009	0.012	0.016	0.015	0.016	0.015	0.036	0.042	0.043	0.040	0.045	0.037	0.041	0.042
0.091	0.072	0.061	0.056	0.051	0.046	0.034	0.024	0.019	0.015	0.014	0.012	0.005	0.000	0.003	0.006	0.011	0.014	0.012	0.014	0.012	0.033	0.039	0.040	0.037	0.042	0.034	0.038	0.039
0.094	0.075	0.063	0.057	0.052	0.047	0.036	0.025	0.020	0.017	0.015	0.013	0.006	0.003	0.000	0.003	0.008	0.011	0.009	0.011	0.009	0.033	0.039	0.040	0.037	0.041	0.034	0.037	0.039
0.097	0.077	0.066	0.060	0.055	0.050	0.039	0.028	0.023	0.019	0.018	0.016	0.009	0.006	0.003	0.000	0.008	0.009	0.006	0.009	0.007	0.031	0.037	0.038	0.034	0.039	0.032	0.035	0.037
0.100	0.081	0.061	0.055	0.050	0.045	0.035	0.025	0.019	0.021	0.014	0.011	0.012	0.011	0.008	0.008	0.000	0.005	0.011	0.010	0.011	0.035	0.042	0.043	0.039	0.043	0.036	0.039	0.041
0.104	0.084	0.065	0.059	0.054	0.049	0.039	0.030	0.024	0.026	0.019	0.016	0.016	0.014	0.011	0.009	0.005	0.000	0.008	0.006	0.008	0.034	0.043	0.044	0.041	0.041	0.034	0.037	0.039
0.103	0.084	0.072	0.066	0.061	0.056	0.045	0.034	0.029	0.025	0.024	0.022	0.015	0.012	0.009	0.006	0.011	0.008	0.000	0.003	0.001	0.027	0.035	0.037	0.033	0.034	0.027	0.030	0.032
0.105	0.085	0.070	0.064	0.059	0.054	0.043	0.033	0.029	0.025	0.024	0.020	0.016	0.014	0.011	0.009	0.010	0.006	0.003	0.000	0.003	0.029	0.038	0.039	0.036	0.036	0.028	0.032	0.033
0.104	0.084	0.072	0.066	0.061	0.056	0.045	0.033	0.029	0.025	0.024	0.022	0.015	0.012	0.009	0.007	0.011	0.008	0.001	0.003	0.000	0.027	0.035	0.036	0.033	0.033	0.026	0.030	0.031
0.105	0.087	0.080	0.072	0.067	0.063	0.054	0.045	0.043	0.041	0.041	0.041	0.036	0.033	0.033	0.031	0.035	0.034	0.027	0.029	0.027	0.000	0.010	0.013	0.014	0.009	0.013	0.015	0.017
0.101	0.093	0.086	0.080	0.075	0.070	0.060	0.051	0.049	0.047	0.047	0.047	0.042	0.039	0.039	0.037	0.042	0.043	0.035	0.038	0.035	0.010	0.000	0.006	0.007	0.008	0.017	0.013	0.015
0.099	0.095	0.087	0.082	0.076	0.072	0.061	0.052	0.050	0.048	0.048	0.048	0.043	0.040	0.040	0.038	0.043	0.044	0.037	0.039	0.036	0.013	0.006	0.000	0.004	0.012	0.016	0.011	0.013
0.099	0.093	0.086	0.080	0.075	0.070	0.059	0.048	0.047	0.045	0.044	0.045	0.040	0.037	0.037	0.034	0.039	0.041	0.033	0.036	0.033	0.014	0.007	0.004	0.000	0.013	0.013	0.009	0.011
0.109	0.095	0.088	0.081	0.076	0.071	0.062	0.053	0.051	0.049	0.049	0.049	0.045	0.042	0.041	0.039	0.043	0.041	0.034	0.036	0.033	0.009	0.008	0.012	0.013	0.000	0.014	0.012	0.015
0.109	0.093	0.086	0.080	0.075	0.070	0.059	0.046	0.045	0.043	0.042	0.042	0.037	0.034	0.034	0.032	0.036	0.034	0.027	0.028	0.026	0.013	0.017	0.016	0.013	0.014	0.000	0.005	0.007
0.108	0.097	0.090	0.084	0.079	0.074	0.063	0.050	0.048	0.046	0.045	0.046	0.041	0.038	0.037	0.035	0.039	0.037	0.030	0.032	0.030	0.015	0.013	0.011	0.009	0.012	0.005	0.000	0.003
0.109	0.100	0.092	0.087	0.082	0.077	0.065	0.052	0.049	0.047	0.047	0.047	0.042	0.039	0.039	0.037	0.041	0.039	0.032	0.033	0.031	0.017	0.015	0.013	0.011	0.015	0.007	0.003	0.000

Table A2. Intensity of changes in the structure (NPS) of investment outlays in mining enterprises in Poland in 1993–2020.

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
0.000	0.094	0.392	0.446	0.385	0.379	0.429	0.427	0.437	0.205	0.313	0.405	0.414	0.401	0.346	0.343	0.370	0.330	0.373	0.333	0.379	0.362	0.387	0.402	0.424	0.381	0.419	0.380
0.094	0.000	0.318	0.387	0.312	0.284	0.335	0.333	0.343	0.175	0.283	0.310	0.319	0.307	0.252	0.249	0.275	0.270	0.278	0.239	0.320	0.303	0.328	0.308	0.330	0.287	0.325	0.286
0.392	0.318	0.000	0.147	0.164	0.139	0.285	0.230	0.272	0.432	0.547	0.253	0.252	0.293	0.322	0.320	0.323	0.412	0.298	0.306	0.433	0.475	0.419	0.347	0.352	0.279	0.279	0.344
0.446	0.387	0.147	0.000	0.087	0.144	0.313	0.243	0.214	0.460	0.575	0.238	0.200	0.322	0.350	0.348	0.351	0.440	0.326	0.334	0.461	0.503	0.447	0.375	0.381	0.302	0.255	0.372
0.385	0.312	0.164	0.087	0.000	0.085	0.249	0.182	0.140	0.373	0.488	0.150	0.113	0.234	0.263	0.261	0.263	0.353	0.239	0.247	0.373	0.416	0.359	0.287	0.293	0.215	0.168	0.284
0.379	0.284	0.139	0.144	0.085	0.000	0.203	0.135	0.158	0.316	0.446	0.118	0.123	0.177	0.206	0.204	0.207	0.296	0.182	0.190	0.317	0.359	0.303	0.231	0.236	0.158	0.140	0.228
0.429	0.335	0.285	0.313	0.249	0.203	0.000	0.091	0.167	0.288	0.480	0.145	0.174	0.076	0.090	0.128	0.129	0.138	0.113	0.156	0.147	0.197	0.133	0.063	0.068	0.154	0.160	0.059
0.427	0.333	0.230	0.243	0.182	0.135	0.091	0.000	0.084	0.291	0.483	0.062	0.091	0.084	0.108	0.121	0.108	0.212	0.123	0.138	0.224	0.288	0.219	0.132	0.138	0.081	0.078	0.129
0.437	0.343	0.272	0.214	0.140	0.158	0.167	0.084	0.000	0.280	0.470	0.043	0.034	0.132	0.167	0.156	0.144	0.260	0.160	0.145	0.272	0.336	0.267	0.168	0.180	0.094	0.046	0.177
0.205	0.175	0.432	0.460	0.373	0.316	0.288	0.291	0.280	0.000	0.192	0.257	0.264	0.240	0.198	0.182	0.208	0.165	0.211	0.172	0.210	0.194	0.218	0.240	0.263	0.220	0.258	0.230
0.313	0.283	0.547	0.575	0.488	0.446	0.480	0.483	0.470	0.192	0.000	0.449	0.456	0.431	0.390	0.367	0.393	0.350	0.396	0.357	0.388	0.302	0.402	0.425	0.448	0.404	0.443	0.422
0.405	0.310	0.253	0.238	0.150	0.118	0.145	0.062	0.043	0.257	0.449	0.000	0.040	0.101	0.125	0.124	0.113	0.228	0.129	0.116	0.241	0.304	0.235	0.137	0.148	0.064	0.025	0.136
0.414	0.319	0.252	0.200	0.113	0.123	0.174	0.091	0.034	0.264	0.456	0.040	0.000	0.135	0.160	0.159	0.150	0.262	0.163	0.148	0.275	0.338	0.269	0.175	0.182	0.102	0.055	0.172
0.401	0.307	0.293	0.322	0.234	0.177	0.076	0.084	0.132	0.240	0.431	0.101	0.135	0.000	0.055	0.067	0.053	0.127	0.065	0.081	0.140	0.203	0.134	0.053	0.062	0.077	0.094	0.063
0.346	0.252	0.322	0.350	0.263	0.206	0.090	0.108	0.167	0.198	0.390	0.125	0.160	0.055	0.000	0.050	0.049	0.103	0.053	0.082	0.116	0.180	0.113	0.069	0.085	0.085	0.132	0.054
0.343	0.249	0.320	0.348	0.261	0.204	0.128	0.121	0.156	0.182	0.367	0.124	0.159	0.067	0.050	0.000	0.041	0.104	0.030	0.032	0.130	0.180	0.138	0.084	0.102	0.063	0.110	0.102
0.370	0.275	0.323	0.351	0.263	0.207	0.129	0.108	0.144	0.208	0.393	0.113	0.150	0.053	0.049	0.041	0.000	0.118	0.044	0.055	0.129	0.198	0.132	0.070	0.086	0.050	0.098	0.091
0.330	0.270	0.412	0.440	0.353	0.296	0.138	0.212	0.260	0.165	0.350	0.228	0.262	0.127	0.103	0.104	0.118	0.000	0.114	0.114	0.058	0.081	0.058	0.108	0.119	0.166	0.213	0.104
0.373	0.278	0.298	0.326	0.239	0.182	0.113	0.123	0.160	0.211	0.396	0.129	0.163	0.065	0.053	0.030	0.044	0.114	0.000	0.053	0.135	0.181	0.124	0.086	0.100	0.067	0.114	0.105
0.333	0.239	0.306	0.334	0.247	0.190	0.156	0.138	0.145	0.172	0.357	0.116	0.148	0.081	0.082	0.032	0.055	0.114	0.053	0.000	0.155	0.193	0.163	0.116	0.130	0.071	0.111	0.134
0.379	0.320	0.433	0.461	0.373	0.317	0.147	0.224	0.272	0.210	0.388	0.241	0.275	0.140	0.116	0.130	0.129	0.058	0.135	0.155	0.000	0.108	0.014	0.105	0.097	0.179	0.226	0.104
0.362	0.303	0.475	0.503	0.416	0.359	0.197	0.288	0.336	0.194	0.302	0.304	0.338	0.203	0.180	0.180	0.198	0.081	0.181	0.193	0.108	0.000	0.113	0.168	0.180	0.242	0.290	0.168
0.387	0.328	0.419	0.447	0.359	0.303	0.133	0.219	0.267	0.218	0.402	0.235	0.269	0.134	0.113	0.138	0.132	0.058	0.124	0.163	0.014	0.113	0.000	0.099	0.091	0.173	0.220	0.099
0.402	0.308	0.347	0.375	0.287	0.231	0.063	0.132	0.168	0.240	0.425	0.137	0.175	0.053	0.069	0.084	0.070	0.108	0.086	0.116	0.105	0.168	0.099	0.000	0.024	0.094	0.121	0.025
0.424	0.330	0.352	0.381	0.293	0.236	0.068	0.138	0.180	0.263	0.448	0.148	0.182	0.062	0.085	0.102	0.086	0.119	0.100	0.130	0.097	0.180	0.091	0.024	0.000	0.118	0.133	0.044
0.381	0.287	0.279	0.302	0.215	0.158	0.154	0.081	0.094	0.220	0.404	0.064	0.102	0.077	0.085	0.063	0.050	0.166	0.067	0.071	0.179	0.242	0.173	0.094	0.118	0.000	0.047	0.116
0.419	0.325	0.279	0.255	0.168	0.140	0.160	0.078	0.046	0.258	0.443	0.025	0.055	0.094	0.132	0.110	0.098	0.213	0.114	0.111	0.226	0.290	0.220	0.121	0.133	0.047	0.000	0.142
0.380	0.286	0.344	0.372	0.284	0.228	0.059	0.129	0.177	0.230	0.422	0.136	0.172	0.063	0.054	0.102	0.091	0.104	0.105	0.134	0.104	0.168	0.099	0.025	0.044	0.116	0.142	0.000

Table A3. Intensity of changes in the structure (NPS) of the sales in mining enterprises in Poland in 1992–2020.

1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
0.000	0.001	0.003	0.035	0.042	0.078	0.133	0.103	0.111	0.107	0.071	0.156	0.196	0.226	0.218	0.255	0.242	0.293	0.250	0.258	0.269	0.251	0.280	0.257	0.234	0.256	0.297	0.317	0.396
0.001	0.000	0.004	0.035	0.042	0.079	0.133	0.104	0.112	0.107	0.072	0.156	0.197	0.226	0.218	0.255	0.242	0.294	0.250	0.259	0.269	0.252	0.281	0.258	0.235	0.256	0.297	0.318	0.397
0.003	0.004	0.000	0.032	0.039	0.075	0.130	0.100	0.109	0.104	0.069	0.153	0.193	0.223	0.215	0.252	0.238	0.290	0.247	0.255	0.266	0.248	0.278	0.254	0.232	0.253	0.294	0.315	0.393
0.035	0.035	0.032	0.000	0.028	0.050	0.105	0.075	0.081	0.072	0.043	0.129	0.166	0.195	0.186	0.220	0.214	0.265	0.215	0.230	0.234	0.217	0.246	0.222	0.200	0.221	0.262	0.283	0.368
0.042	0.042	0.039	0.028	0.000	0.045	0.108	0.064	0.097	0.089	0.059	0.145	0.178	0.204	0.196	0.233	0.213	0.252	0.228	0.235	0.247	0.229	0.259	0.235	0.213	0.234	0.275	0.296	0.355
0.078	0.079	0.075	0.050	0.045	0.000	0.062	0.025	0.055	0.046	0.022	0.104	0.135	0.159	0.151	0.188	0.168	0.215	0.183	0.189	0.202	0.184	0.213	0.190	0.167	0.189	0.230	0.250	0.318
0.133	0.133	0.130	0.105	0.108	0.062	0.000	0.045	0.035	0.036	0.076	0.064	0.083	0.099	0.095	0.129	0.119	0.161	0.120	0.127	0.140	0.122	0.151	0.128	0.105	0.127	0.167	0.188	0.264
0.103	0.104	0.100	0.075	0.064	0.025	0.045	0.000	0.058	0.047	0.047	0.107	0.126	0.141	0.138	0.171	0.158	0.190	0.164	0.171	0.183	0.166	0.195	0.172	0.149	0.170	0.211	0.232	0.293
0.111	0.112	0.109	0.081	0.097	0.055	0.035	0.058	0.000	0.017	0.047	0.050	0.092	0.120	0.111	0.146	0.139	0.191	0.140	0.155	0.160	0.142	0.171	0.148	0.125	0.147	0.187	0.208	0.293
0.107	0.107	0.104	0.072	0.089	0.046	0.036	0.047	0.017	0.000	0.041	0.062	0.099	0.128	0.120	0.151	0.148	0.197	0.145	0.162	0.162	0.144	0.173	0.150	0.127	0.149	0.190	0.210	0.300
0.071	0.072	0.069	0.043	0.059	0.022	0.076	0.047	0.047	0.041	0.000	0.086	0.132	0.167	0.158	0.189	0.185	0.237	0.185	0.202	0.203	0.185	0.214	0.191	0.168	0.190	0.231	0.251	0.340
0.156	0.156	0.153	0.129	0.145	0.104	0.064	0.107	0.050	0.062	0.086	0.000	0.055	0.118	0.113	0.142	0.143	0.200	0.145	0.164	0.163	0.139	0.157	0.136	0.110	0.140	0.178	0.193	0.299
0.196	0.197	0.193	0.166	0.178	0.135	0.083	0.126	0.092	0.099	0.132	0.055	0.000	0.066	0.061	0.090	0.091	0.148	0.093	0.111	0.110	0.087	0.105	0.084	0.058	0.088	0.126	0.141	0.247
0.226	0.226	0.223	0.195	0.204	0.159	0.099	0.141	0.120	0.128	0.167	0.118	0.066	0.000	0.009	0.036	0.033	0.083	0.032	0.046	0.053	0.034	0.063	0.042	0.039	0.040	0.080	0.101	0.182
0.218	0.218	0.215	0.186	0.196	0.151	0.095	0.138	0.111	0.120	0.158	0.113	0.061	0.009	0.000	0.040	0.033	0.088	0.037	0.051	0.058	0.038	0.068	0.046	0.044	0.044	0.085	0.105	0.187
0.255	0.255	0.252	0.220	0.233	0.188	0.129	0.171	0.146	0.151	0.189	0.142	0.090	0.036	0.040	0.000	0.028	0.058	0.027	0.021	0.026	0.017	0.030	0.026	0.050	0.030	0.045	0.066	0.157
0.242	0.242	0.238	0.214	0.213	0.168	0.119	0.158	0.139	0.148	0.185	0.143	0.091	0.033	0.033	0.028	0.000	0.058	0.044	0.030	0.052	0.041	0.058	0.054	0.057	0.057	0.065	0.086	0.157
0.293	0.294	0.290	0.265	0.252	0.215	0.161	0.190	0.191	0.197	0.237	0.200	0.148	0.083	0.088	0.058	0.058	0.000	0.056	0.037	0.045	0.064	0.069	0.069	0.091	0.072	0.063	0.072	0.103
0.250	0.250	0.247	0.215	0.228	0.183	0.120	0.164	0.140	0.145	0.185	0.145	0.093	0.032	0.037	0.027	0.044	0.056	0.000	0.023	0.024	0.014	0.043	0.023	0.037	0.024	0.048	0.071	0.155
0.258	0.259	0.255	0.230	0.235	0.189	0.127	0.171	0.155	0.162	0.202	0.164	0.111	0.046	0.051	0.021	0.030	0.037	0.023	0.000	0.022	0.031	0.042	0.037	0.058	0.039	0.041	0.065	0.138
0.269	0.269	0.266	0.234	0.247	0.202	0.140	0.183	0.160	0.162	0.203	0.163	0.110	0.053	0.058	0.026	0.052	0.045	0.024	0.022	0.000	0.028	0.030	0.033	0.055	0.036	0.033	0.057	0.139
0.251	0.252	0.248	0.217	0.229	0.184	0.122	0.166	0.142	0.144	0.185	0.139	0.087	0.034	0.038	0.017	0.041	0.064	0.014	0.031	0.028	0.000	0.030	0.013	0.035	0.016	0.047	0.067	0.160
0.280	0.281	0.278	0.246	0.259	0.213	0.151	0.195	0.171	0.173	0.214	0.157	0.105	0.063	0.068	0.030	0.058	0.069	0.043	0.042	0.030	0.030	0.000	0.023	0.052	0.030	0.023	0.038	0.145
0.257	0.258	0.254	0.222	0.235	0.190	0.128	0.172	0.148	0.150	0.191	0.136	0.084	0.042	0.046	0.026	0.054	0.069	0.023	0.037	0.033	0.013	0.023	0.000	0.030	0.011	0.043	0.060	0.166
0.234	0.235	0.232	0.200	0.213	0.167	0.105	0.149	0.125	0.127	0.168	0.110	0.058	0.039	0.044	0.050	0.057	0.091	0.037	0.058	0.055	0.035	0.052	0.030	0.000	0.032	0.068	0.083	0.191
0.256	0.256	0.253	0.221	0.234	0.189	0.127	0.170	0.147	0.149	0.190	0.140	0.088	0.040	0.044	0.030	0.057	0.072	0.024	0.039	0.036	0.016	0.030	0.011	0.032	0.000	0.047	0.064	0.161
0.297	0.297	0.294	0.262	0.275	0.230	0.167	0.211	0.187	0.190	0.231	0.178	0.126	0.080	0.085	0.045	0.065	0.063	0.048	0.041	0.033	0.047	0.023	0.043	0.068	0.047	0.000	0.025	0.141
0.317	0.318	0.315	0.283	0.296	0.250	0.188	0.232	0.208	0.210	0.251	0.193	0.141	0.101	0.105	0.066	0.086	0.072	0.071	0.065	0.057	0.067	0.038	0.060	0.083	0.064	0.025	0.000	0.147
0.396	0.397	0.393	0.368	0.355	0.318	0.264	0.293	0.293	0.300	0.340	0.299	0.247	0.182	0.187	0.157	0.157	0.103	0.155	0.138	0.139	0.160	0.145	0.166	0.191	0.161	0.141	0.147	0.000

Table A4. Intensity of changes in the structure(NPS) of net fixed assets in mining enterprises in Poland in 2004–2020.

2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
0.000	0.013	0.027	0.006	0.024	0.052	0.057	0.060	0.076	0.071	0.074	0.063	0.058	0.073	0.014	0.043	0.046
0.013	0.000	0.015	0.015	0.013	0.040	0.046	0.048	0.065	0.060	0.063	0.056	0.058	0.072	0.017	0.030	0.034
0.027	0.015	0.000	0.029	0.009	0.026	0.032	0.034	0.051	0.046	0.058	0.056	0.059	0.072	0.031	0.016	0.019
0.006	0.015	0.029	0.000	0.022	0.049	0.056	0.059	0.075	0.070	0.075	0.064	0.061	0.078	0.010	0.044	0.047
0.024	0.013	0.009	0.022	0.000	0.028	0.036	0.038	0.055	0.050	0.061	0.059	0.062	0.079	0.025	0.025	0.028
0.052	0.040	0.026	0.049	0.028	0.000	0.008	0.012	0.027	0.022	0.061	0.059	0.062	0.080	0.051	0.026	0.020
0.057	0.046	0.032	0.056	0.036	0.008	0.000	0.009	0.019	0.014	0.059	0.058	0.064	0.082	0.053	0.030	0.024
0.060	0.048	0.034	0.059	0.038	0.012	0.009	0.000	0.016	0.011	0.059	0.059	0.071	0.091	0.051	0.032	0.027
0.076	0.065	0.051	0.075	0.055	0.027	0.019	0.016	0.000	0.007	0.064	0.069	0.083	0.096	0.067	0.048	0.043
0.071	0.060	0.046	0.070	0.050	0.022	0.014	0.011	0.007	0.000	0.059	0.064	0.078	0.095	0.062	0.043	0.038
0.074	0.063	0.058	0.075	0.061	0.061	0.059	0.059	0.064	0.059	0.000	0.011	0.023	0.039	0.067	0.059	0.060
0.063	0.056	0.056	0.064	0.059	0.059	0.058	0.059	0.069	0.064	0.011	0.000	0.014	0.032	0.058	0.058	0.058
0.058	0.058	0.059	0.061	0.062	0.062	0.064	0.071	0.083	0.078	0.023	0.014	0.000	0.019	0.068	0.061	0.061
0.073	0.072	0.072	0.078	0.079	0.080	0.082	0.091	0.096	0.095	0.039	0.032	0.019	0.000	0.087	0.068	0.069
0.014	0.017	0.031	0.010	0.025	0.051	0.053	0.051	0.067	0.062	0.067	0.058	0.068	0.087	0.000	0.045	0.048
0.043	0.030	0.016	0.044	0.025	0.026	0.030	0.032	0.048	0.043	0.059	0.058	0.061	0.068	0.045	0.000	0.007
0.046	0.034	0.019	0.047	0.028	0.020	0.024	0.027	0.043	0.038	0.060	0.058	0.061	0.069	0.048	0.007	0.000

Table A5. Intensity of changes in the structure (NPS) of electricity generation in Poland in 1990–2020.

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
0.000	0.013	0.015	0.017	0.011	0.011	0.018	0.017	0.019	0.021	0.033	0.030	0.035	0.035	0.043	0.054	0.078	0.089	0.073	0.086	0.097	0.113	0.139	0.131	0.154	0.177	0.185	0.196	0.202	0.246	0.286
0.013	0.000	0.003	0.005	0.009	0.022	0.028	0.026	0.021	0.027	0.045	0.039	0.045	0.049	0.051	0.065	0.090	0.100	0.079	0.089	0.109	0.113	0.139	0.131	0.155	0.178	0.186	0.197	0.204	0.247	0.287
0.015	0.003	0.000	0.003	0.008	0.021	0.028	0.027	0.021	0.027	0.045	0.038	0.044	0.050	0.052	0.067	0.092	0.102	0.081	0.091	0.110	0.113	0.139	0.130	0.154	0.177	0.185	0.196	0.202	0.246	0.286
0.017	0.005	0.003	0.000	0.010	0.024	0.030	0.029	0.023	0.029	0.047	0.040	0.047	0.052	0.054	0.069	0.093	0.104	0.083	0.092	0.112	0.112	0.139	0.131	0.154	0.177	0.185	0.197	0.203	0.247	0.286
0.011	0.009	0.008	0.010	0.000	0.015	0.022	0.021	0.014	0.020	0.037	0.030	0.038	0.043	0.046	0.061	0.086	0.096	0.075	0.085	0.104	0.110	0.137	0.129	0.152	0.174	0.182	0.194	0.200	0.244	0.284
0.011	0.022	0.021	0.024	0.015	0.000	0.009	0.009	0.015	0.013	0.024	0.023	0.028	0.030	0.039	0.051	0.073	0.083	0.069	0.082	0.093	0.109	0.135	0.127	0.150	0.173	0.182	0.192	0.198	0.242	0.282
0.018	0.028	0.028	0.030	0.022	0.009	0.000	0.005	0.018	0.013	0.017	0.021	0.025	0.026	0.035	0.047	0.064	0.075	0.065	0.078	0.089	0.105	0.132	0.124	0.148	0.170	0.178	0.190	0.196	0.240	0.280
0.017	0.026	0.027	0.029	0.021	0.009	0.005	0.000	0.015	0.010	0.019	0.019	0.023	0.024	0.033	0.047	0.067	0.076	0.063	0.077	0.087	0.103	0.131	0.123	0.147	0.169	0.176	0.189	0.195	0.239	0.279
0.019	0.021	0.021	0.023	0.014	0.015	0.018	0.015	0.000	0.008	0.028	0.020	0.029	0.034	0.037	0.054	0.077	0.086	0.065	0.075	0.094	0.101	0.129	0.121	0.145	0.167	0.175	0.188	0.195	0.239	0.278
0.021	0.027	0.027	0.029	0.020	0.013	0.013	0.010	0.008	0.000	0.020	0.013	0.022	0.026	0.029	0.047	0.070	0.079	0.059	0.073	0.087	0.099	0.127	0.119	0.142	0.165	0.173	0.186	0.192	0.236	0.275
0.033	0.045	0.045	0.047	0.037	0.024	0.017	0.019	0.028	0.020	0.000	0.016	0.015	0.016	0.027	0.041	0.052	0.061	0.056	0.071	0.080	0.097	0.125	0.116	0.139	0.161	0.169	0.182	0.188	0.232	0.272
0.030	0.039	0.038	0.040	0.030	0.023	0.021	0.019	0.020	0.013	0.016	0.000	0.010	0.014	0.019	0.037	0.060	0.069	0.049	0.063	0.076	0.092	0.120	0.111	0.135	0.156	0.164	0.177	0.183	0.227	0.267
0.035	0.045	0.044	0.047	0.038	0.028	0.025	0.023	0.029	0.022	0.015	0.010	0.000	0.007	0.013	0.028	0.051	0.061	0.043	0.057	0.068	0.086	0.114	0.105	0.128	0.151	0.159	0.171	0.177	0.221	0.261
0.035	0.049	0.050	0.052	0.043	0.030	0.026	0.024	0.034	0.026	0.016	0.014	0.007	0.000	0.015	0.029	0.046	0.055	0.041	0.056	0.065	0.085	0.113	0.104	0.127	0.149	0.157	0.169	0.176	0.220	0.260
0.043	0.051	0.052	0.054	0.046	0.039	0.035	0.033	0.037	0.029	0.027	0.019	0.013	0.015	0.000	0.020	0.042	0.053	0.033	0.047	0.061	0.076	0.104	0.096	0.119	0.141	0.150	0.162	0.169	0.213	0.252
0.054	0.065	0.067	0.069	0.061	0.051	0.047	0.047	0.054	0.047	0.041	0.037	0.028	0.029	0.020	0.000	0.029	0.041	0.022	0.034	0.047	0.062	0.091	0.083	0.106	0.129	0.137	0.150	0.157	0.201	0.240
0.078	0.090	0.092	0.093	0.086	0.073	0.064	0.067	0.077	0.070	0.052	0.060	0.051	0.046	0.042	0.029	0.000	0.012	0.031	0.034	0.046	0.062	0.093	0.093	0.111	0.129	0.137	0.150	0.156	0.201	0.239
0.089	0.100	0.102	0.104	0.096	0.083	0.075	0.076	0.086	0.079	0.061	0.069	0.061	0.055	0.053	0.041	0.012	0.000	0.035	0.038	0.039	0.056	0.096	0.096	0.115	0.123	0.130	0.143	0.150	0.194	0.233
0.073	0.079	0.081	0.083	0.075	0.069	0.065	0.063	0.065	0.059	0.056	0.049	0.043	0.041	0.033	0.022	0.031	0.035	0.000	0.017	0.034	0.044	0.072	0.064	0.088	0.111	0.119	0.132	0.138	0.183	0.223
0.086	0.089	0.091	0.092	0.085	0.082	0.078	0.077	0.075	0.073	0.071	0.063	0.057	0.056	0.047	0.034	0.034	0.038	0.017	0.000	0.024	0.030	0.061	0.061	0.080	0.098	0.106	0.120	0.126	0.170	0.209
0.097	0.109	0.110	0.112	0.104	0.093	0.089	0.087	0.094	0.087	0.080	0.076	0.068	0.065	0.061	0.047	0.046	0.039	0.034	0.024	0.000	0.034	0.074	0.073	0.092	0.099	0.095	0.115	0.121	0.160	0.199
0.113	0.113	0.113	0.112	0.110	0.109	0.105	0.103	0.101	0.099	0.097	0.092	0.086	0.085	0.076	0.062	0.062	0.056	0.044	0.030	0.034	0.000	0.041	0.046	0.062	0.068	0.078	0.102	0.108	0.144	0.181
0.139	0.139	0.139	0.139	0.137	0.135	0.132	0.131	0.129	0.127	0.125	0.120	0.114	0.113	0.104	0.091	0.093	0.096	0.072	0.061	0.074	0.041	0.000	0.020	0.027	0.044	0.066	0.090	0.094	0.132	0.169
0.131	0.131	0.130	0.131	0.129	0.127	0.124	0.123	0.121	0.119	0.116	0.111	0.105	0.104	0.096	0.083	0.093	0.096	0.064	0.061	0.073	0.046	0.020	0.000	0.024	0.050	0.065	0.087	0.092	0.129	0.164
0.154	0.155	0.154	0.154	0.152	0.150	0.148	0.147	0.145	0.142	0.139	0.135	0.128	0.127	0.119	0.106	0.111	0.115	0.088	0.080	0.092	0.062	0.027	0.024	0.000	0.029	0.051	0.073	0.077	0.114	0.150
0.177	0.178	0.177	0.177	0.174	0.173	0.170	0.169	0.167	0.165	0.161	0.156	0.151	0.149	0.141	0.129	0.129	0.123	0.111	0.098	0.099	0.068	0.044	0.050	0.029	0.000	0.029	0.049	0.060	0.090	0.127
0.185	0.186	0.185	0.185	0.182	0.182	0.178	0.176	0.175	0.173	0.169	0.164	0.159	0.157	0.150	0.137	0.137	0.130	0.119	0.106	0.095	0.078	0.066	0.065	0.051	0.029	0.000	0.029	0.034	0.069	0.109
0.196	0.197	0.196	0.197	0.194	0.192	0.190	0.189	0.188	0.186	0.182	0.177	0.171	0.169	0.162	0.150	0.150	0.143	0.132	0.120	0.115	0.102	0.090	0.087	0.073	0.049	0.029	0.000	0.035	0.053	0.092
0.202	0.204	0.202	0.203	0.200	0.198	0.196	0.195	0.195	0.192	0.188	0.183	0.177	0.176	0.169	0.157	0.156	0.150	0.138	0.126	0.121	0.108	0.094	0.092	0.077	0.060	0.034	0.035	0.000	0.048	0.091
0.246	0.247	0.246	0.247	0.244	0.242	0.240	0.239	0.239	0.236	0.232	0.227	0.221	0.220	0.213	0.201	0.201	0.194	0.183	0.170	0.160	0.144	0.132	0.129	0.114	0.090	0.069	0.053	0.048	0.000	0.044
0.286	0.287	0.286	0.286	0.284	0.282	0.280	0.279	0.278	0.275	0.272	0.267	0.261	0.260	0.252	0.240	0.239	0.233	0.223	0.209	0.199	0.181	0.169	0.164	0.150	0.127	0.109	0.092	0.091	0.044	0.000

Table A6. Results of the univariate regression analysis (significant results only).

Dependent Variables	**Independent Variables (Explanatory Variables)**							
	Constant	**Coefficient**	**Pearson**	**Standard Error of Regression**	**R-Squared**	***p*-Value**	**F Statistics (F-Value)**	**Observations**
				NPS EN				
NPS EMPN	0.188	−0.071	0.705	0.015	0.496	0.000	25.637	28
NPS FA	0.033	0.103	0.701	0.004	0.491	0.041	1.261	16
NPS SCO	0.086	1.125	0.846	0.057	0.716	0.000	65.581	28
SCE	41,000.760	−30,194.844	0.661	2745.697	0.437	0.000	20.922	29
TP	120,245.936	−285,045.130	0.884	12,096.489	0.781	0.000	96.061	29
PCO	98,946.869	−233,262.379	0.919	8,025.344	0.844	0.000	146.150	29
				NPS EMPN				
NPS FA	0.098	0.085	0.385	0.005	0.148	0.000	2.437	16
				NPS IO				
NPS EMPN	0.064	0.074	0.328	0.016	0.108	0.001	3.012	28
NPS FA	0.063	−0.041	0.080	0.025	0.003	0.005	0.036	16
TP	68,104.311	61,423.965	0.303	18,673.687	0.092	0.013	2.519	28
PpU	0.712	0.498	0.298	0.119	0.089	0.000	2.429	28
				NPS FA				
NPS EMPN	0.098	0.085	0.385	0.005	0.148	0.000	2.437	16
TP	84,490.058	−190,457.361	0.395	10,935.424	0.156	0.000	2.586	16
PpU	0.981	−0.630	0.199	0.076	0.040	0.000	0.580	16
				FA				
PCO	27,960.320	−0.160	0.866	2384.262	0.750	0.000	81.151	29
				IO				
FA	6257.254	0.004	0.741	2205.773	0.549	0.000	32.824	29
				NPS IO				
rFA	0.118	0.137	0.317	0.092	0.101	0.000	2.796	28

References

1. Tutak, M.; Brodny, J.; Siwiec, D.; Ulewicz, R.; Bindzár, P. Studying the Level of Sustainable Energy Development of the European Union Countries and Their Similarity Based on the Economic and Demographic Potential. *Energies* **2020**, *13*, 6643. [CrossRef]
2. Rodrigues, J.F.D.; Wang, J.; Behrens, P.; de Boer, P. Drivers of CO_2 emissions from electricity generation in the European Union 2000–2015. *Renew. Sustain. Energy Rev.* **2020**, *133*, 110104. [CrossRef]
3. Kaczmarek, J.; Krzemiński, P.; Litwa, P.; Szymla, W. *Procesy Zmian W Okresie Transformacji Systemowej. Prywatyzacja, Restrukturyzacja, Rynek Kapitałowy (Processes of Change during Systemic Transformation. Privatization, Restructuring, Capital Market)*; Wydawnictwo Akademii Ekonomicznej w Krakowie: Kraków, Poland, 2005; pp. 102–103.
4. Fischer, S.; Sahay, R.; Vegh, C.A. Stabilization and Growth in Transition Economies: The Early Experience. *J. Econ. Perspect.* **1996**, *10*, 45–66. [CrossRef]
5. Blanchard, O. Assesment of the Economic Transition in Central and Eastern Europe—Theoretical Aspects of Transition. *Am. Econ. Rev.* **1996**, *86*, 117–122. Available online: https://www.jstor.org/stable/i337086 (accessed on 12 January 2022).
6. Åslund, A.; Boone, P.; Johnson, S. How to Stabilize: Lessons from Post-Communist Countries. *Brook. Pap. Econ. Act.* **1996**, *1*, 217–313. [CrossRef]
7. Kuznets, S. Economic Growth of Nations. In *Total Output and Production Structure*; HUP Belknap Press Imprint: Cambridge, UK, 2013; pp. 10–18.
8. Kaczmarek, J. The Role of Structural Policies in Counteracting the Crisis. In *Moving from the Crisis to Sustainability. Emerging Issues in the International Context*; Calabro, G., D'Amico, A., Lanfranchi, M., Moschella, G., Pulejo, L., Salomone, R., Eds.; Edizioni Franco Angeli: Milano, Italy, 2011; pp. 45–54.
9. Peres, W.; Primi, A. *Theory and Practice of Industrial Policy: Evidence from the Latin American Experience*; UN Cepal: Santiago, Chile, 2009; Volume 187, pp. 1–51. Available online: https://www.cepal.org/en/publications/4582-theory-and-practice-industrial-policy-evidence-latin-american-experience (accessed on 12 January 2022).
10. Kaczmarek, J. The Stance, Factors, and Composition of Competitiveness of SMEs in Poland. *Sustainability* **2022**, *14*, 1788. [CrossRef]
11. Hübner, D. Transformacja i rozwój (Transformation and development). In *Gospodarka Polski W Procesie Transformacji*; IRiSS: Warszawa, Poland, 1992; p. 153.
12. Koźmiński, A.; Obłój, K. *Zarys Teorii Równowagi Organizacyjnej (Outline of Organizational Balance Theory)*; PWE: Warszawa, Poland, 1989; ISBN 832080728X.
13. Singh, H. Challenges in Researching Corporate Restructuring. *J. Manag. Stud.* **1993**, *30*, 147–172. [CrossRef]
14. Stoner, J.A.F.; Freeman, R.E.; Gilbert, D.R. *Management*; Prentice Hall: Hoboken, NJ, USA, 1995; pp. 260–269.
15. Griffin, R.W. *Management*; Cengage Learning: Boston, MA, USA, 2016; pp. 392–397.
16. Porter, M.E. *Competitive Adventage: Creating and Sustaining Superiorer Performance*; The Free Press: New York, NY, USA, 1998; pp. 50–62.
17. Slatter, S. *Corporate Recovery: A Guide to Turnaround Management*; Penguin Business: London, UK, 1984; pp. 81–92.
18. Copeland, T.; Koller, T.; Murrin, J. *Valuation—Measuring and Managing the Values of Companies*; John Wiley Sons: New York, NY, USA, 2000; pp. 301–308.
19. Danovi, A.; Magno, F.; Dossena, G. Pursuing Firm Economic Sustainability through Debt Restructuring Agreements in Italy: An Empirical Analysis. *Sustainability* **2018**, *10*, 4830. [CrossRef]
20. Ho, L.-H.; Tsai, C.-C. A Model Constructed to Evaluate Sustainable Operation and Development of State-Owned Enterprises after Restructuring. *Sustainability* **2018**, *10*, 2354. [CrossRef]
21. Lis, A. Typologia restrukturyzacji (Typology of restructuring). *Przegląd Organ.* **2004**, *4*, 9–12. [CrossRef]
22. Nogalski, B.; Hałaczkiewicz, M.; Witt, J. *Restrukturyzacja Procesowa W Zarządzaniu Małymi I Średnimi Przedsiębiorstwami (Process-oriented Restructuring in the Management of Small and Medium Enterprises)*; OPO TNOiK: Bydgoszcz, Poland, 1999; pp. 10–23.
23. Kaczmarek, J. The concept and Measurement of Creating Excess Value in Listed Companies. *Eng. Econ.* **2018**, *29*, 1392–2785. [CrossRef]
24. Gajdzik, B.; Gawlik, R. Choosing the Production Function Model for an Optimal Measurement of the Restructuring Efficiency of the Polish Metallurgical Sector in Years 2000–2015. *Metals* **2018**, *8*, 23. [CrossRef]
25. Christensen, C.M.; Marx, M.; Stevenson, H.H. The tools of cooperation and change. *Harv. Bus. Rev.* **2006**, *84*, 72–80. Available online: https://hbr.org/2006/10/the-tools-of-cooperation-and-change (accessed on 8 January 2022). [PubMed]
26. Kaczmarek, J. The Mechanisms of Creating Value vs. Financial Security of Going Concern-Sustainable Management. *Sustainability* **2019**, *11*, 2278. [CrossRef]
27. Slatter, S.; Lovett, D. *Restrukturyzacja Firmy. Zarządzanie Przedsiębiorstwem W Sytuacjach Kryzysowych (Restructuring of Enterprise. Managing a Company in Crisis Situations)*; WIG-Press: Warszawa, Poland, 2001; pp. 42–48.
28. Mączyńska, E. Upadłość przedsiębiorstw w kontekście ekonomii kryzysu (Bankruptcy of enterprises in the context of crisis economics). In *Zarządzanie Przedsiębiorstwem W Kryzysie*; Morawska, S., Ed.; SGH: Warszawa, Poland, 2011; pp. 10–31.
29. Kaczmarek, J. Measurement of Creating Corporate Value for Shareholders—Development of Measurements and Improvement of Management Competence and Skills. *Pol. J. Manag. Stud.* **2014**, *9*, 72–83. Available online: http://oaji.net/articles/2014/1384-1416997716.pdf (accessed on 21 January 2022).

30. Platt, H.D.; Platt, M.B. Predicting Corporate Financial Distress: Reflection on Choice-Based Sample Bias. *J. Econ. Financ.* **2002**, *26*, 184–199. [CrossRef]
31. Altman, E.I.; Narayanan, P. An International Survey of Business Failure Classification Models. *Financ. Mark. Inst. Instrum.* **1997**, *6*, 1–57. [CrossRef]
32. Pociecha, J. Model logitowy jako narzędzie prognozowania bankructwa—Jego zalety i wady (The logit model as a tool for predicting bankruptcy—Its advantages and disadvantages). In *Spotkania Z Królową Nauk*; Malawski, A., Tatar, J., Eds.; Uniwersytet Ekonomiczny w Krakowie: Kraków, Poland, 2012; pp. 60–74.
33. Pavitt, K. Sectoral patterns of technical change: Towards a taxonomy and a theory. *Res. Policy* **1984**, *13*, 343–374. [CrossRef]
34. Timmer, M.P.; Szirmai, A. Productivity Growth in Asian Manufacturing: The structural bonus hypothesis examined. *Struct. Chang. Econ. Dyn.* **2000**, *11*, 371–392. [CrossRef]
35. Kukuła, K. *Statystyczne Metody Analizy Struktur Ekonomicznych (Statistical Methods of the Analysis of Economic Structures)*; Wydawnictwo Edukacyjne: Cracow, Poland, 1996; pp. 9, 15–17.
36. Hambrick, D.C. Taxonomic approaches to studying strategy: Some conceptual and methodological issues. *J. Manag.* **1984**, *10*, 27–41. [CrossRef]
37. Consoli, D.; Rentocchini, F. A taxonomy of multi-industry labour force skills. *Res. Policy* **2015**, *44*, 1116–1132. [CrossRef]
38. Archibugi, D. Pavitt's taxonomy sixteen years on: A review article. *Econ. Innov. New Technol.* **2001**, *3*, 415–425. [CrossRef]
39. Kotelska, J. Restructuring Conditions for Traditional Industry Enterprises in Poland. *Zesz. Naukowe. Organ. I Zarządzanie/Politech. Śląska* **2019**, *134*, 93–108. [CrossRef]
40. Brauers, H.; Oei, P.-Y.; Walk, P. Comparing coal phase-out pathways: The United Kingdom's and Germany's diverging transitions. *Environ. Innov. Soc. Transit.* **2020**, *37*, 238–253. [CrossRef] [PubMed]
41. Burns, A.; Winterton, J.; Newby, M. The restructuring of the British coal industry. *Camb. J. Econ.* **1985**, *9*, 93–110. [CrossRef]
42. Turnheim, B.; Geels, F.W. The destabilisation of existing regimes: Confronting a multi-dimensional framework with a case study of the British Coal Industry (1913–1967). *Res. Policy* **2013**, *42*, 1749–1767. [CrossRef]
43. Sovacool, B.K.; Noel, L.; Orsato, R.J. Stretching, embeddedness, and scripts in a sociotechnical transition: Explaining the failure of electric mobility at better place (2007–2013). *Technol. Forecast. Soc. Chang.* **2017**, *123*, 24–34. [CrossRef]
44. Bankier.pl, Kontrowersje Wokół Budowy Pierwszej Od 34 Lat Kopalni Węgla Kamiennego W Wielkiej Brytanii (Controversy over the Construction of the First Hard Coal Mine in Great Britain in 34 Years). Available online: https://www.bankier.pl/wiadomosc/Wielka-Brytania-rozwaza-budowe-pierwszej-od-34-lat-kopalni-wegla-Beda-konsultacje-publiczne-8073599.html (accessed on 21 January 2022).
45. Oei, P.-Y.; Brauers, H.; Herpich, P. Lessons from Germany's hard coal mining phase-out: Policies and transition from 1950 to 2018. *Clim. Policy* **2020**, *20*, 963–979. [CrossRef]
46. Ohlhorst, D. Germany's energy transition policy between national targets and decentralized responsibilities. *J. Integr. Environ. Sci.* **2015**, *12*, 303–322. [CrossRef]
47. Rogge, K.S.; Pfluger, B.; Geels, F.W. Transformative policy mixes in socio-technical scenarios: The case of the low-carbon transition of the German electricity system (2010–2050). *Technol. Forecast. Soc. Chang.* **2020**, *151*, 119259. [CrossRef]
48. Jonek-Kowalska, I.; Wolny, M.; Sojda, A. Analiza trendów i korelacji cen węgla kamiennego na rynkach międzynarodowych w erze dekarbonizacji (Analysis of coal prices trends and correlations in international markets in era of decarbonization). *Zesz. Nauk. Politech. Śląskiej Ser. Organ. I Zarządzanie* **2014**, *74*, 185–197. Available online: https://bibliotekanauki.pl/articles/323139 (accessed on 21 January 2022).
49. PEP 2040. Polityka Energetyczna Polski Do 2040 Roku. (PEP 2040. Energy Policy of Poland until 2030). Ministerstwo Klimatu I Środowiska, Warsaw, February 2021. Available online: https://www.gov.pl/attachment/62a054de-0a3d-444d-a969-90a89502df94 (accessed on 22 February 2022).
50. Eurostat. Eurostat Data Browser. Production of Electricity and Derived Heat by Type of Fuel. Available online: https://ec.europa.eu/eurostat/databrowser/explore/all/envir?lang=en&subtheme=nrg.nrg_quant.nrg_quanta.nrg_bal&display=list&sort=category&extractionId=NRG_BAL_PEH__custom_2069571 (accessed on 22 February 2022).
51. Toborek-Mazur, J.; Wójcik-Jurkiewicz, M. Multi-Energy Concern as an Example of the Implementation of Agenda 2030: Poland as a Case Study. *Energies* **2022**, *15*, 1669. [CrossRef]
52. Kryk, B.; Guzowska, M.K. Implementation of Climate/Energy Targets of the Europe 2020 Strategy by the EU Member States. *Energies* **2021**, *14*, 2711. [CrossRef]
53. Gadowska, K. *The Phenomenon of Political and Economic Clientelism: A Systemic Analysis of the Network Connections in the Case of the Transformation of the Mining Sector in Poland*; Wydawnictwo Uniwersytetu Jagiellońskiego: Cracow, Poland, 2002.
54. Czech, A. Conditions of Polish Energy Policy in the Context of Sustainable Development Postulate. *Studia Ekon.* **2016**, *269*, 50–61. Available online: https://www.ue.katowice.pl/fileadmin/user_upload/wydawnictwo/SE_Artyku%C5%82y_251_270/SE_269/04.pdf (accessed on 22 February 2022).
55. Wensierski, P. Poszerzenie Unii Europejskiej: Proces akcesji Polski (Enlargement of the European Union: The process of Poland's accession). *Słupskie Studia Hist.* **2003**, *10*, 227–248. Available online: https://bazhum.muzhp.pl/media/files/Slupskie_Studia_Historyczne/Slupskie_Studia_Historyczne-r2003-t10/Slupskie_Studia_Historyczne-r2003-t10-s227-248/Slupskie_Studia_Historyczne-r2003-t10-s227-248.pdf (accessed on 22 February 2022).

56. European Commission. Directive 2001/80/EC. Available online: https://eur-lex.europa.eu/legal-content/PL/ALL/?uri=CELEX%3A32001L0080 (accessed on 22 February 2022).
57. European Commission. Directive 2001/77/EC. Available online: https://eur-lex.europa.eu/legal-content/PL/ALL/?uri=CELEX%3A32001L0077 (accessed on 22 February 2022).
58. European Commission. 2020 Climate & Energy Package. Available online: https://ec.europa.eu/clima/eu-action/climate-strategies-targets/2020-climate-energy-package_en (accessed on 22 February 2022).
59. Szymla, W. Influence of the Climate and Energy Package on the Conditions of Functioning of the Power Sector Enterprises in Poland. In *Contemporary Economies in the Face of New Challenges: Economic, Social and Legal Aspects*; Borowiecki, R., Jaki, A., Rojek, T., Eds.; Foundation of the Cracow University of Economics: Cracow, Poland, 2013; pp. 751–761.
60. Kowalke, K.; Prochownik, M. The Impact of Climate and Energy Package on the Process of Modernization the Polish Energy Sector. *J. Manag. Financ.* **2014**, *12*, 229–245. Available online: http://zif.wzr.pl/pim/2014_4_15.pdf (accessed on 22 February 2022).
61. Liobikienė, G.; Butkus, M. The European Union possibilities to achieve targets of Europe 2020 and Paris agreement climate policy. *Renew. Energy* **2017**, *106*, 298–309. [CrossRef]
62. Rosenow, J.; Cowart, R.; Bayer, E.; Fabbri, M. Assessing the European Union's energy efficiency policy: Will the winter package deliver on 'Efficiency First'? *Energy Res. Soc. Sci.* **2017**, *26*, 72–79. [CrossRef]
63. European Commission. Delivering the European Green Deal. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en#key-steps (accessed on 22 February 2022).
64. European Commission. Fit for 55% Package. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550 (accessed on 22 February 2022).
65. European Commission. Directive 2003/87/EC. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32003L0087 (accessed on 22 February 2022).
66. Verbruggen, A.; Laes, E.; Woerdman, E. Anatomy of Emissions Trading Systems: What is the EU ETS? *Environ. Sci. Policy* **2019**, *98*, 11–19. [CrossRef]
67. Szymla, W. The effects of the restructuring of power sector companies in terms of maintaining the energy security in Poland after 1989. *Zarządzanie Publiczne* **2013**, *4*, 20–33. Available online: https://zarzadzaniepubliczne.pl/index.php/zpub/article/view/280/195 (accessed on 22 February 2022).
68. ZPEP 1990-2010. Założenia Polityki Energetycznej Polski Na Lata 1990–2010 (PEP 1990–2010. Energy Policy of Poland for 1990–2010). Available online: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WMP19900430332 (accessed on 22 February 2022).
69. ZPEP 2010. Założenia Polityki Energetycznej Polski Do 2010 R. (PEP 2010. Energy Policy of Poland until 2010). Dokument Rządowy, Warsaw, October 1995. Available online: https://www.prawo.pl/akty/m-p-1990-43-332,16823035.html (accessed on 22 February 2022).
70. PEP 2020. Założenia Polityki Energetycznej Polski Do 2020 r (PEP 2020. Energy Policy of Poland until 2020), Warsaw, February 2000. Available online: http://bazekon.icm.edu.pl/bazekon/element/bwmeta1.element.ekon-element-000000109211 (accessed on 22 February 2022).
71. PEP 2025. Polityka Energetyczna Polski Do 2025 Roku. (PEP 2025. Energy Policy of Poland until 2025). Ministerstwo Gospodarki I Pracy, Warsaw, July 2005. Available online: https://sip.lex.pl/akty-prawne/mp-monitor-polski/polityka-energetyczna-panstwa-do-2025-r-17205399 (accessed on 22 February 2022).
72. PEP 2030. Polityka Energetyczna Polski Do 2030 Roku. (PEP 2030. Energy Policy of Poland until 2030). Ministerstwo Gospodarki, Warsaw, November 2009. Available online: https://sip.lex.pl/akty-prawne/mp-monitor-polski/polityka-energetyczna-panstwa-do-2030-r-17589536 (accessed on 22 February 2022).
73. Europe's Energy Transition: A Common Challenge. Report. Institute Montaigne, September 2021. Available online: https://www.institutmontaigne.org/en/publications/europes-energy-transition-common-challenge (accessed on 22 April 2022).
74. Nies, S. (Ed.) The European Energy Transition. In *Actors, Factors, Sectors*; Claeys & Casteels: Deventer, The Netherland, 2019. Available online: https://author.energy-community.org/enc-author-prd/dam/jcr:9a2c264d-766f-445b-8ffd-1cd1a2893622/SS19_Nies_08_2019.pdf (accessed on 22 April 2022).
75. Tagliapietra, S.; Zachmann, G.; Edenhofer, O.; Glachant, J.M.; Linares, P.; Loeschel, A. The European union energy transition: Key priorities for the next five years. *Energy Policy* **2019**, *132*, 950–954. [CrossRef]
76. Peña-Ramos, J.; del Pino-García, M.; Sánchez-Bayón, A. The Spanish Energy Transition into the EU Green Deal: Alignments and Paradoxes. *Energies* **2021**, *14*, 2535. [CrossRef]
77. Foxon, T. Managing the transition to renewable energy: Theory and practice from local, regional and macro perspectives. *Environ. Sci.* **2008**, *5*, 286–288. [CrossRef]
78. Gawlik, L.; Mokrzycki, E. Changes in the Structure of Electricity Generation in Poland in View of the EU Climate Package. *Energies* **2019**, *12*, 3323. [CrossRef]
79. Grubišić Šeba, M.; Flora, A. Poland's Energy Transition—Caught between Lobbying and Common (Economic) Sense, IEEFA Europe, January 2022. Available online: http://ieefa.org/wp-content/uploads/2022/01/Polands-Energy-Transition-Caught-Between-Lobbying-and-Common-Economic-Sense_January-2022.pdf (accessed on 22 April 2022).
80. Lew, G.; Sadowska, B.; Chudy-Laskowska, K.; Zimon, G.; Wójcik-Jurkiewicz, M. Influence of Photovoltaic Development on Decarbonization of Power Generation—Example of Poland. *Energies* **2021**, *14*, 7819. [CrossRef]

81. Bednorz, J. Charakterystyka programów rządowych w latach 1989–2010 i ich wpływ na producentów węgla kamiennego w Polsce (Characteristics of government programs in 1989–2010 and their impact on hard coal producers in Poland). In *Bezpieczeństwo Energetyczne—Rynki Surowców I Energii*; Kwiatkiewicz, P., Ed.; Wydawnictwo Wyższej Szkoły Bezpieczeństwa: Poznań, Poland, 2011; pp. 207–237.
82. Marszowski, R. Działania restrukturyzacyjne wobec górnictwa węgla kamiennego i ich wpływ na otoczenie społeczno-gospodarcze. Stan i perspektywy (Restructuring actions to coal mining and its impact on socio-economic environment. State and perspectives). *Humanum. Int. J. Soc. Humanit. Stud.* **2017**, *3*, 113–124. Available online: http://cejsh.icm.edu.pl/cejsh/element/bwmeta1.element.mhp-2470d1d5-c621-4986-9992-9c917edbcd06 (accessed on 25 April 2022).
83. Paszcza, H. Procesy restrukturyzacji w polskim górnictwie węgla kamiennego w aspekcie zrealizowanych przemian i zmiany bazy zasobowej (Restructuring processes in the Polish hard coal mining industry in terms of the implemented changes and changes in the resource base). *Górnictwo I Geoinżynieria* **2010**, *34*, 63–82. Available online: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-AGHM-0014-0004 (accessed on 25 April 2022).
84. Zabierowski, J. Wybrane problemy restrukturyzacji polskiego górnictwa węgla kamiennego (Selected problems of restructuring of the Polish hard coal mining industry). *Wiadomości Górnicze* **1996**, *3*, 5–9.
85. Kamola-Cieślik, M. Bezpieczeństwo energetyczne Polski a sytuacja ekonomiczna Kompanii Węglowej SA po 2014 roku (Poland's energy security and the economic situation of Kompania Węglowa SA after 2014). *Bezpieczeństwo. Teor. I Prakt.* **2016**, *1*, 133–148. Available online: http://hdl.handle.net/11315/20277 (accessed on 25 April 2022).
86. Karbownik, A.; Wodarski, K. Efekty restrukturyzacji polskiego górnictwa węgla kamiennego w latach 1990–2004 (The effects of restructuring of the Polish hard coal mining industry in 1990–2004). *Wiadomości Górnicze* **2005**, *56*, 274–281. Available online: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BGPK-1139-4504?q=bwmeta1.element.baztech-volume-0043-5120-wiadomosci_gornicze-2005-vol__56_nr_6;0&qt=CHILDREN-STATELESS (accessed on 25 April 2022).
87. Tkocz, M. Efekty restrukturyzacji górnictwa węgla kamiennego w Polsce (Effects of restructuring of the hard coal mining industry in Poland). *Pr. Kom. Geogr. Przemysłu* **2006**, *9*, 28–39. Available online: http://cejsh.icm.edu.pl/cejsh/element/bwmeta1.element.desklight-f7429231-225e-4197-ba15-1b528977bdb9 (accessed on 25 April 2022).
88. Przybyłka, A. Spadek zatrudnienia wśród górników węgla kamiennego w kolejnych etapach restrukturyzacji branży na Górnym Śląsku (Decline in employment among hard coal miners in the subsequent stages of industry restructuring in Upper Silesia). *Studia I Materiały. Misc. Oeconomicae* **2011**, *1*, 99–108. Available online: https://tuudi.net/wp-content/uploads/2017/03/A.-Przyby%C5%82ka-Spadek-zatrudnienia-w%C5%9Br%C3%B3d-g%C3%B3rnik%C3%B3w-w%C4%99gla-kamiennego-w-kolejnych-etapach-restrukturyzacji-bran%C5%BCy-na-G%C3%B3rnym-%C5%9Al%C4%85sku..pdf (accessed on 25 April 2022).
89. Bluszcz, A.; Kijewska, A.; Sojda, A. Analiza efektywności zarządzania wartością przedsiębiorstwa górniczego (Analysis of the effectiveness of managing the value of a mining enterprise). *Zesz. Nauk. Uniw. Szczecińskiego. Finans. Rynk. Finans. Ubezpieczenia* **2013**, *64*, 87–96. Available online: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.ekon-element-000171281001 (accessed on 25 April 2022).
90. Sojda, A. Perspektywy i zagrożenia dla rozwoju zasobów ludzkich w górnictwie węgla kamiennego (Prospects and threats for the development of human resources in hard coal mining). *Studia Ekon.* **2014**, *196*, 185–195. Available online: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.ekon-element-000171355831 (accessed on 25 April 2022).
91. Gumiński, A.; Karbownik, A.; Wodarski, K.; Jędrychowski, S. Restrukturyzacja zatrudnienia w polskim górnictwie węgla kamiennego w latach 1998–2006 (Employment restructuring in the Polish hard coal mining industry in 1998–2006). *Wiadomości Górnicze* **2008**, *59*, 166–174. Available online: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BGPK-2100-7971?q=bwmeta1.element.baztech-volume-0043-5120-wiadomosci_gornicze-2008-vol__59_nr_3;0&qt=CHILDREN-STATELESS (accessed on 25 April 2022).
92. Hibner, M. Restrukturyzacja zatrudnienia w górnictwie węgla kamiennego w latach 2004–2014 (Employment restructuring in the hard coal mining industry in 2004–2014). *Zesz. Nauk. Państwowej Wyższej Szkoły Zawodowej Im. Witelona W Legn.* **2016**, *19*, 39–50. Available online: https://bazhum.muzhp.pl/czasopismo/449/?idvol=11224 (accessed on 25 April 2022).
93. Jonek-Kowalska, I. Koszty produkcji w polskim górnictwie węgla kamiennego (Production costs in the Polish hard coal mining). In *Analiza I Ocena Kosztów W Górnictwie Węgla Kamiennego W Polsce W Aspekcie Poprawy Efektywności Wydobycia*; Turek, M., Ed.; Difin: Warszawa, Poland, 2013; pp. 45–56. ISBN 978-83-7641-825-4.
94. Turek, M.; Jonek-Kowalska, I.; Ganszczyk, Z. *Determinanty Innowacyjności W Przedsiębiorstwach Górniczych (Determinants of Innovation in Mining Enterprises)*; Politechnika Śląska: Gliwice, Poland, 2016. Available online: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BSL3-0024-0084 (accessed on 25 April 2022).
95. Jonek-Kowalska, I. Challenges for long-term industry restructuring in the Upper Silesian Coal Basin: What has Polish coal mining achieved and failed from a twenty-year perspective? *Resour. Policy* **2015**, *44*, 135–149. [CrossRef]
96. Rybak, A. The strategy of flexible mining in conditions of seasonal demand for hard coal (Strategia elastycznego wydobycia w warunkach sezonowości popytu na węgiel kamienny). *Wiadomości Górnicze* **2014**, *65*, 227–233.
97. Wendt, R. *Change Management in a Polish Company (Zarzadzanie Zmianą W Polskiej Firmie)*; Dom Wydawniczy Zachorek: Warsaw, Poland, 2010. Available online: https://wendt.pl/images/files/Zarzadzanie_zmiana_bezplatny_fragment.pdf (accessed on 25 April 2022).

98. *Analiza I Ocena Kosztów W Górnictwie Węgla Kamiennego W Polsce W Aspekcie Poprawy Efektywności Wydobycia (Analysis and Evaluation of Costs in the Hard Coal Mining Industry in Poland in Terms of Improving Mining Efficiency)*; Turek, M. (Ed.) Difin: Warszawa, Poland, 2013; ISBN 978-83-7641-825-4.
99. Sojda, A. Analiza statystyczna wskaźników finansowych dla przedsiębiorstw górniczych (Statistical analysis of financial indicators for mining enterprises). *Organ. I Zarządzanie. Zesz. Nauk. Politech. Śląskiej* **2014**, *68*, 255–264. Available online: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-235fe354-121b-4c8d-9abe-54ab7c70b65a (accessed on 25 April 2022).
100. Turowski, K. Unowocześnienie struktury gospodarczej jako czynnik wzrostu produktywności w polskiej gospodarce (Modernization of the economic structure as a factor of productivity growth in the Polish economy). In *Problemy Gospodarowania W Dobie Globalizacji*; Kunasz, M., Ed.; Print Group, Daniel Krzanowski: Szczecin, Poland, 2006; pp. 145–157. ISBN 8360065942.
101. Cellura, M.; Longo, S.; Mistretta, M. Application of the Structural Decomposition Analysis to assess the indirect energy consumption and air emission changes related to Italian households consumption. *Renew. Sustain. Energy Rev.* **2012**, *16*, 1135–1145. [CrossRef]
102. Barba, I.; Iraizoz, B. Effect of the Great Crisis on Sectoral Female Employment in Europe: A Structural Decomposition Analysis. *Economies* **2020**, *8*, 64. [CrossRef]
103. Barcik, R.; Dziwiński, P. Społecznie odpowiedzialna restrukturyzacja zatrudnienia. *Pr. Nauk. Uniw. Ekon. We Wrocławiu* **2016**, *419*, 21–32. [CrossRef]
104. Pierścionek, Z. *Strategie Rozwoju Firmy (Company Development Strategies)*; Wydawnictwo Naukowe PWN: Warszawa, Poland, 1996; ISBN 8301119802.
105. Cascio, W.F. Strategies for responsible restructuring. *Acad. Manag. Perspect.* **2002**, *16*, 80–91. [CrossRef]
106. Chomątowski, S. Warunki a czynniki rozwoju przedsiębiorstwa. Próba identyfikacji i klasyfikacji (Conditions and factors of enterprise development. An attempt to identify and classify). In *Restrukturyzacja W Procesie Przekształceń I Rozwoju Przedsiębiorstw*; Borowiecki, R., Ed.; Towarzystwo Naukowe Organizacji i Kierownictwa: Kraków, Poland, 1996; pp. 174–175. Available online: http://www.nukat.edu.pl/nukat/icov/WALAZ/zz2007825000.pdf (accessed on 25 April 2022).
107. Gabrusewicz, W. Rozwój przedsiębiorstw przemysłowych i jego ocena w gospodarce rynkowej (Development of industrial enterprises and its evaluation in the market economy). *Zesz. Nauk. Akad. Ekon. W Pozn.* **1992**, *120*, 197. Available online: https://www.wbc.poznan.pl/dlibra/publication/97731/edition/109494/content (accessed on 25 April 2022).
108. Fijorek, K.; Kaczmarek, J.; Kolegowicz, K.; Krzemiński, P. Ocena zagrożenia przedsiębiorstw upadłością—Koncepcja systemowa ISR (Evaluation of enterprise bankruptcy risk—A systemic concept of ISR). *Przegląd Organ.* **2015**, *4*, 18–25. [CrossRef]
109. Antonowicz, P. *Metody Oceny I Kondycji Ekonomiczno-Finansowej Przedsiębiorstw (Methods of Evaluating the Economic and Financial Condition of Enterprises)*; ODiDK: Gdańsk, Poland, 2007; pp. 31–42.
110. Juszczyk, S. Prognozowanie upadłości przedsiębiorstw (Forecasting enterprise bankruptcy). *Ekonomista* **2010**, *5*, 701–728. Available online: http://bazekon.icm.edu.pl/bazekon/element/bwmeta1.element.ekon-element-000168325184 (accessed on 21 January 2022).
111. Prusak, B. *Nowoczesne Metody Prognozowania Zagrożenia Finansowego Przedsiębiorstw (Modern Methods of Forecasting Enterprise Financial Threats)*; Difin: Warszawa, Poland, 2005; pp. 129–172.
112. Jajuga, K. Statystyczne modele wczesnego ostrzegania—Metody Formalne (Statistical models of early warning—Formal Methods). *Barom. Reg.* **2006**, *6*, 52–55. Available online: http://br.wszia.edu.pl/zeszyty/pdfs/br06_07jajuga.pdf (accessed on 25 April 2022).
113. Gavurova, B.; Packova, M.; Misankova, M.; Smrcka, L. Predictive potential and risks of selected bankruptcy prediction models in the Slovak business environment. *J. Bus. Econ. Manag.* **2017**, *18*, 1156–1173. [CrossRef]
114. Hosmer, D.W.; Lemeshow, S. *Applied Logistic Regression*; Wiley: New York, NY, USA, 1989; pp. 145–162.
115. Fijorek, K.; Fijorek, D. Dobór zmiennych objaśniających metodą najlepszego podzbioru do modelu regresji logistycznej Firtha (Selection of Explanatory Variables Using the Best Subset Method for Firth's Logistic Regression Model. *Metod. Inform. Stosow.* **2011**, *2*, 15–24. Available online: http://www.pan.wi.zut.edu.pl/mispdf/MIS-2011-2.pdf (accessed on 11 January 2022).
116. Long, S.J. *Regression Models for Categorical and Limited Dependent Variables*; Thousand Oaks, SAGE Publications: London, UK, 1997; pp. 56–68.
117. Hafiz, A.A.; Lukumon, O.O.; Hakeem, A.O.; Vikas, K.; Saheed, O.A.; Olugbenga, O.A.; Muhammad, B. Systematic review of bankruptcy prediction models: Towards a framework for tool selection. *Expert Syst. Appl.* **2018**, *94*, 164–184. [CrossRef]
118. Fijorek, K.; Denkowska, S.; Kaczmarek, J.; Náñez Alonso, S.L.; Sokołowski, A. Financial threat profiles of industrial enterprises in Poland. *Oeconomia Copernic.* **2021**, *12*, 463–498. [CrossRef]
119. Heinze, G.; Schemper, M. A solution to the problem of separation in logistic regression. *Stat. Med.* **2002**, *21*, 2409–2419. [CrossRef] [PubMed]
120. Firth, D. Bias reduction of maximum likelihood estimates. *Biometrika* **1993**, *80*, 27–38. [CrossRef]
121. Fijorek, K.; Sokołowski, A. Separation-Resistant and Bias-Reduced Logistic Regression: STATISTICA macro. *J. Stat. Softw.* **2012**, *47*, 1–12. [CrossRef]
122. Hadasik, D. Upadłość przedsiębiorstw w Polsce i metody jej prognozowania (Bankruptcy of enterprises in Poland and the methods of its forecasting). *Zesz. Nauk. Akad. Ekon. W Pozn.* **1998**, *153*, 1–198. Available online: www.wbc.poznan.pl:115723 (accessed on 9 January 2022).

123. Zelek, A. Wczesna identyfikacja kryzysu ucieczką od bankructwa (Early identification of a crisis as an escape from bankruptcy). *Przegląd Organ.* **2002**, *2*, 32–36. Available online: http://www.przegladorganizacji.pl/plik/375/po200202pdf (accessed on 14 January 2022). [CrossRef]
124. Fijorek, K.; Kaczmarek, J.; Kolegowicz, K.; Krzemiński, P. Bankruptcy Risk Assessment—A Microeconomic Perspective. In *The Rapid Response Instrument to Bankruptcy Risk in the Non-Financial Sector. Design and Implementation*; Boguszewski, P.A., Ed.; Polish Agency for Enterprise Development: Warsaw, Poland, 2014; pp. 117–131.
125. Piłatowska, M. *Repetytorium Ze Statystyki (Repertory of Statistics)*; Wydawnictwo Naukowe PWN: Warszawa, Poland, 2006.
126. Higgins, R.C.; Koski, J.L.; Mitton, T. *Analysis for Financial Management*, 12th ed.; McGraw-Hill Education: New York, NY, USA, 2019; pp. 35–89.
127. Block, S.; Hirt, G.; Danielsen, B. *Foundations of Financial Management*, 17th ed.; McGraw-Hill Education: New York, NY, USA, 2019; pp. 250–348.
128. Dudycz, T.; Wrzosek, S. *Analiza Finansowa. Problemy Metodyczne W Ujęciu Praktycznym (Financial Analysis. Methodological Problems in a Practical Approach)*; Wydawnictwo Akademii Ekonomicznej we Wrocławiu: Wrocław, Poland, 2000; pp. 124–168.
129. Chomątowski, S. (Ed.) *Dynamika I Kierunki Zmian Wielkości I Struktury Sektora Przedsiębiorstw W Polsce W Latach 1990–2005*; Fundacja Uniwersytetu Ekonomicznego w Krakowie: Kraków, Poland, 2009; p. 39.
130. Kukuła, K. Propozycja w zakresie pewnych miar dynamiki struktur (A proposal for certain measures of the dynamics of structures). *Przegląd Stat.* **1975**, *3*, 453–461.
131. Archibugi, D.; Pianta, M. Measuring technological change through patents and innovation surveys. *Technovation* **1996**, *9*, 451–468. [CrossRef]
132. Castellacci, F. Technological paradigms, regimes and trajectories: Manufacturing and service industries in a new taxonomy of sectoral patterns of innovation. *Res. Policy* **2008**, *37*, 978–994. Available online: https://www.files.ethz.ch/isn/32006/719_TechnologicalParadigms.pdf (accessed on 25 April 2022). [CrossRef]
133. Chomątowski, S.; Sokołowski, A. Taksonomia struktur (Taxonomy of structures). *Przegląd Stat.* **1978**, *2*, 217–226.
134. Kamiński, J. *Siła Rynkowa W Krajowym Sektorze Wytwarzania Energii Elektrycznej—Zagadnienia Wybrane (Market Power in the Domestic Electricity Generation Sector—Selected Issues)*; Wydawnictwo IGSMiE PAN: Kraków, Poland, 2012.
135. Szpor, A. Coal Transition in Poland. An Historical Case Study for the Project Coal Transitions: Research and Dialogue on the Future of Coal. *IDDRI Clim. Strat.* **2017**. Available online: https://www.iddri.org/sites/default/files/PDF/Publications/Catalogue%20Iddri/Rapport/201706-iddri-climatestrategies-reportcoal_pl.pdf (accessed on 11 January 2022).
136. Karbownik, A.; Wodarski, K.; Turek, M. Wpływ procesów restrukturyzacyjnych w latach 1989–2000 na kształtowanie się wielkości parametrów struktury i modelu kopalń węgla kamiennego (The impact of restructuring processes in 1989–2000 on the shaping of the parameters of the structure and model of hard coal mines). In *Restrukturyzacja Górnictwa a Struktura Kopalń Węgla Kamiennego*; Główny Instytut Górnictwa: Katowice, Poland, 2002; p. 11.
137. Rybak, A.; Rybak, A. Possible strategies for hard coal mining in Poland as a result of production function analysis. *Resour. Policy* **2016**, *50*, 27–33. [CrossRef]
138. Blaschke, W.; Gawlik, L.; Lorenz, U. Perspektywy górnictwa węgla kamiennego po przystąpieniu Polski do Unii Europejskiej w świetle realizowanych programów restrukturyzacyjnych (Perspectives of hard coal mining after Poland's accession to the European Union in the light of the implemented restructuring programs). In *Proceedings of the XIV Konferencja Z Cyklu Aktualia I Perspektywy Gospodarki Surowcami Mineralnymi W Zakopanem, Sympozja I Konferencje Nr 63*; Wyd. Instytutu GSMiE PAN: Kraków, Poland, 2004; pp. 15–27.
139. Stalewski, T.; Szpak, A. *Likwidowanie Kopalń Węgla Kamiennego W Małym Mieście Górniczym (Closure of Hard Coal Mines in a Small Mining Town). Studia Regionalne i Lokalne nr 4*; Uniwersytet Warszawski: Warszawa, Poland, 2000.
140. Szczepański, M.S. Górnicy Nie Przepuścili Odpraw. Często Brakowało im Jednak Qiedzy (The Miners Did Not Miss the Severance Pay. However, They Often Lacked Knowledge), *Dziennik Zachodni*, 12 January 2015. Available online: https://dziennikzachodni.pl/prof-szczepanski-gornicy-nie-przepuscili-odpraw-czesto-brakowalo-im-jednak-wiedzy/ar/c3-3711606 (accessed on 11 January 2022).
141. Fornalczyk, A.; Choroszczak, L.; Mikulec, M. *Restrukturyzacja Górnictwa Węgla Kamiennego (Restructuring of Hard Coal Mining)*; Poltext: Warszawa, Poland, 2008; pp. 34–52.
142. Sejm Rzeczpospolitej Polskiej, Ustawa Z Dnia 26.11.1998 r. o Dostosowaniu Górnictwa Węgla Kamiennego Do Funkcjonowania W Warunkach Gospodarki Rynkowej Oraz Szczególnych Uprawnieniach I Zadaniach Gmin Górniczych, Wraz Z Późniejszymi Zmianami (Dz.U.1998, nr 162, Poz.1112). Available online: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU19981621112 (accessed on 22 February 2022).
143. Sejm Rzeczpospolitej Polskiej, Ustawa Dnia 28.11.2003 r. o Restrukturyzacji Górnictwa Węgla Kamiennego W Latach 2003–2006 (Dz. U. nr 120, Poz.2037). Available online: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20032102037 (accessed on 22 February 2022).
144. Paszcza, H.; Madejski, A. Górnictwo węgla kamiennego w Polsce w 2003 roku (Hard Coal Industry in Poland in 2005), Wiadomości Górnicze 2004, 6, 249. Available online: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BGPK-1398-5383 (accessed on 22 February 2022).
145. Bednarski, L.; Borowiecki, R.; Duraj, J.; Kurtys, E.; Waśniewski, T.; Wersty, B. *Analiza Ekonomiczna W Przedsiębiorstwie (Economic Analysis in the Enterprise)*; Wydawnictwo Akademii Ekonomicznej we Wrocławiu: Wrocław, Poland, 1995.

146. *Restructuring and Privatizing the Coal Industries in Central and Eastern Europe and the CIS*; World Energy Council: London, UK, 2000; pp. 1–199. Available online: https://www.worldenergy.org/assets/downloads/PUB_Restructuring_and_privatizing_coal_in_CIES_2004_WEC.pdf (accessed on 28 January 2022).
147. Dubiński, J.; Turek, M. Wybrane aspekty zmian restrukturyzacyjnych w polskim górnictwie węgla kamiennego w latach 1990–2008 (Selected aspects of restructuring changes in Polish hard coal mining in 1990–2008). *Res. Rep. Min. Environ.* **2009**, *2*, 5–19. Available online: https://kwartalnik.gig.eu/sites/default/files/articles/prace-naukowe-gig/2009_2_1.pdf (accessed on 24 January 2022).
148. Jonek-Kowalska, I.; Turek, M. Dependence of Total Production Costs on Production and Infrastructure Parameters in the Polish Hard Coal Mining Industry. *Energies* **2017**, *10*, 1480. [CrossRef]
149. Marek, J. Uwarunkowania i przebieg procesu likwidacji kopalń węgla kamiennego (Determinants and the process of hard coal mines liquidation). *Studia Ekon. Akad. Ekon. W Katowicach* **2006**, *37*, 269–283. Available online: https://www.ue.katowice.pl/fileadmin/user_upload/wydawnictwo/SE_Archiwalne/SE_37/18.pdf (accessed on 28 January 2022).
150. Rutledge, D. Estimating long-term world coal production with logit and probit transforms. *Int. J. Coal Geol.* **2011**, *85*, 23–33. [CrossRef]
151. Tkocz, M. Effects of hard coal mining restructuring in Poland. *Stud. Ind. Geogr. Comm. Pol. Geogr. Soc.* **2006**, *9*, 28–39. [CrossRef]
152. Smoliło, J.; Chmiela, A.; Gajdzik, M.; Menéndez, J.; Loredo, J.; Turek, M.; Bernardo-Sánchez, A. A New Method to Analyze the Mine Liquidation Costs in Poland. *Mining* **2021**, *1*, 351–363. [CrossRef]
153. Fuksa, D. Innovative Method for Calculating the Break-Even for Multi-Assortment Production. *Energies* **2021**, *14*, 4213. [CrossRef]
154. Kaczmarek, J. The effectiveness of working capital management strategies in manufacturing enterprises. *Sci. Pap. Sil. Univ. Technol. Organ. Manag.* **2019**, *136*, 191–208. [CrossRef]
155. *Ukryty Rachunek Za Węgiel (Hidden Coal Account)*; WiseEuropa: Warszawa, Poland, 2017; pp. 1–44. Available online: https://wise-europa.eu/2017/09/19/ukryty-rachunek-wegiel-premiera-raportu/ (accessed on 18 January 2022).
156. Rybak, A.; Rybak, A. Analysis of the Main Coal Mining Restructuring Policy Objectives in the Light of Polish Mining Companies' Ability to Change. *Energies* **2020**, *13*, 3281. [CrossRef]
157. Kaczmarek, J. The Balance of Outlays and Effects of Restructuring Hard Coal Mining Companies in Terms of Energy Policy of Poland PEP 2040. *Energies* **2022**, *15*, 1853. [CrossRef]
158. Baran, M.; Kuźniarska, A.; Makieła, Z.J.; Sławik, A.; Stuss, M. Does ESG Reporting Relate to Corporate Financial Performance in the Context of the Energy Sector Transformation? Evidence from Poland. *Energies* **2022**, *15*, 477. [CrossRef]
159. Galos, K.; Lewicka, E.; Burkowicz, A.; Guzik, K.; Kot-Niewiadomska, A.; Kamyk, J.; Szlugaj, J. Approach to identification and classification of the key, strategic and critical minerals important for the mineral security of Poland. *Resour. Policy* **2020**, *70*, 101900. [CrossRef]
160. Kotelska, J. Przesłanki procesu restrukturyzacji górnictwa węgla kamiennego w Polsce (Premises of the restructuring process of the hard coal mining industry in Poland). *ZN WSH Zarządzanie* **2018**, *1*, 207–229.
161. Mokrzycki, E.; Ney, R.; Siemek, J. Światowe zasoby surowców energetycznych. Wnioski dla Polski (Global reserves of energy fossil resources—Conclusions for Poland). *Rynek Energii* **2008**, *6*, 2–13. Available online: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BPL2-0011-0044 (accessed on 22 February 2022).
162. Kaliski, M.; Sikora, A.; Szurlej, A. Węgiel kamienny w polityce energetycznej Polski (Hard coal in Poland's energy policy). *Polityka Energetyczna-Energy Policy J.* **2014**, *17*, 7–18. Available online: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-0d18bd03-a9ef-437f-875d-7dec826e0f52/c/kaliski_in_wegiel_kamienny_17_3.pdf.pdf (accessed on 22 February 2022).
163. Oksińska, B.; Furman, T. Plan rządu dla górnictwa sypie się. Nie ma planu B (The government's plan for mining is falling apart. There is no plan B). *Rzeczpospolita. Ekon. I Rynek* **2005**, *15*, 115.
164. Szlązak, J. *Restrukturyzacja Górnictwa Węgla Kamiennego W Polsce W Latach 1990–2002. Analiza Skuteczności Realizowanych Programów (Restructuring of Hard Coal Mining in Poland in the Years 1990–2002. Analysis of the Effectiveness of Implemented Programs)*; Biblioteka Szkoły Eksploatacji Podziemnej: Kraków, Poland, 2004.
165. Restrukturyzacja. In *Fakty I Opinie (Restructuring. Facts and Opinions)*; Zarząd Główny SITG: Katowice, Poland, 2015.
166. Makieła, Z. Wyniki realizacji programów restrukturyzacji górnictwa węgla kamiennego po 1989 r. (Results of implementation of hard coal mining restructuring programs after 1989). *Pr. Kom. Geogr. Przemysłu Pol. Tow. Geogr.* **2002**, *4*, 57–65. Available online: http://bazekon.icm.edu.pl/bazekon/element/bwmeta1.element.ekon-element-000171298913 (accessed on 25 April 2022).
167. Grmela, A.; Harat, A.; Adamczyk, Z. The process of mines liquidation as an environmental, economic and legal problem. *Ecol. Eng. Environ. Technol.* **2017**, *18*, 39–45. [CrossRef]
168. Gumiński, A. Efektywne wykorzystanie zasobów ludzkich jako kluczowy warunek funkcjonowania przedsiębiorstwa górniczego w perspektywie długoterminowej (Effective use of human resources as a key condition for the functioning of a mining company in the long term). *Organ. I Zarządzanie. Zesz. Nauk. Politech. Śląskiej* **2016**, *89*, 163–176. Available online: https://bibliotekanauki.pl/api/full-texts/2020/12/11/2eb3cc3e-64bf-47c4-8bd2-12f12bfccfbe.pdf (accessed on 25 April 2022).
169. Bluszcz, A. Proces przemian struktury zatrudnienia w górnictwie węgla kamiennego (The process of changes in the employment structure in the hard coal mining industry). *Studia Ekonomiczne. Uniw. Ekon. W Katowicach* **2014**, *196*, 103–113. Available online: http://bazekon.icm.edu.pl/bazekon/element/bwmeta1.element.ekon-element-000171356073 (accessed on 25 April 2022).

170. Gumiński, A. Analiza możliwości zwiększenia efektywności wykorzystania środków produkcji w ścianach wydobywczych kopalni węgla kamiennego (Analysis of the possibilities of increasing the efficiency of the use of production means in the mining walls of a hard coal mine). *Organ. I Zarządzanie. Zesz. Nauk. Politech. Śląskiej* **2015**, *78*, 167–177. Available online: http://bazekon.icm.edu.pl/bazekon/element/bwmeta1.element.ekon-element-000171402853 (accessed on 25 April 2022).
171. Grzybek, J. Restrukturyzacja zatrudnienia w górnictwie węgla kamiennego—Nakłady budżetowe, efekty podjętych działań. (Employment restructuring in the hard coal mining industry—Budget expenditures, effects of actions taken). *Przegląd Górniczy* **2012**, *68*, 63–67. Available online: http://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-b1c9f470-d936-49b1-b162-78d9cbb3ae55?q=0739a17e-cf12-49e3-84b7-4fd19fd2d4b6$2&qt=IN_PAGE (accessed on 25 April 2022).
172. Dołęga, W. Operation security of national distribution grids. *Przegląd Elektrotechniczny* **2020**, *1*, 23–26. [CrossRef]
173. Turek, M.; Jonek-Kowalska, I. Rozwój polskiego górnictwa węglowego w świetle prognozowanych potrzeb energetycznych (Development of the Polish coal mining in the light of forecasted energy needs). *Zesz. Naukowe. Organ. I Zarządzanie/Politech. Śląska* **2015**, *83*, 691–701. Available online: http://bazekon.icm.edu.pl/bazekon/element/bwmeta1.element.ekon-element-000171408367?printView=true (accessed on 25 April 2022).
174. Kamyk, J.; Kot-Niewiadomska, A.; Galos, K. The criticality of crude oil for energy security: A case of Poland. *Energy* **2021**, *220*, 119707. [CrossRef]
175. Stala-Szlugaj, K.; Grudziński, Z. Energy efficiency and steam coal transport over long distances. *ES3 Web Conf.* **2016**, *10*, 00089. [CrossRef]
176. Frankowski, J.; Mazurkiewicz, J.; Sokołowski, J.; Lewandowski, P. Employment in Hard Coal Mining in the Upper Silesian Coal Basin. Zatrudnienie W Górnictwie Węgla Kamiennego W Zagłębiu Górnośląskim. IBS Research Report, Warsaw, Poland, January 2020. Available online: https://ibs.org.pl/app/uploads/2020/09/IBS_Research_Report_01_2020.pdf (accessed on 22 February 2022).
177. Dróżdż, W. The distribution system operator in the era of innovative energy challenges. *Zesz. Nauk. Inst. Gospod. Surowcami Miner. I Energią Pol. Akad. Nauk.* **2018**, *102*, 291–300. Available online: https://min-pan.krakow.pl/wydawnictwo/wp-content/uploads/sites/4/2018/03/20-zn-19-drozdz.pdf (accessed on 22 February 2022).
178. Rusin, A.; Wojaczek, A.; Nawrat, K. Change of the energy system structure and possibilities of energy production by national power units. *Rynek Energii* **2020**, *2*, 3–7. Available online: http://rynek-energii.pl/pl/RE147 (accessed on 22 February 2022).
179. Malec, M. The prospects for decarbonisation in the context of reported resources and energy policy goals: The case of Poland. *Energy Policy* **2022**, *161*, 112763. [CrossRef]
180. Kaliski, M.; Gawlik, L.; Szurlej, A.; Sikora, A.; Kamiński, J. Hard coal in the fuel-mix of Poland: The long perspective. *Arch. Min. Sci.* **2016**, *61*, 335–350. [CrossRef]
181. Bórawski, P.; Bełdycka-Bórawska, A.; Szymańska, E.J.; Jankowski, K.J.; Dubis, B.; Dunn, J.W. Development of renewable energy sources market and biofuels in the European Union. *J. Clean. Prod.* **2019**, *228*, 467–484. [CrossRef]
182. Papież, M.; Śmiech, S.; Frodyma, K. Determinants of renewable energy development in the EU countries. A 20-year perspective. *Renew. Sustain. Energy Rev.* **2018**, *91*, 918–934. [CrossRef]
183. Bonnet, C.; Hache, E.; Seck, G.S.; Simoën, M.; Carcanague, S. Who's winning the low-carbon innovation race? An assessment of countries' leadership in renewable energy technologies. *Int. Econ.* **2019**, *160*, 31–42. [CrossRef]
184. Bel, G.; Joseph, S. Policy stringency under the European Union Emission trading system and its impact on technological change in the energy sector. *Energy Policy* **2018**, *117*, 434–444. [CrossRef]
185. Wierling, A.; Schwanitz, V.J.; Zeiß, J.P.; Bout, C.; Candelise, C.; Gilcrease, W.; Gregg, J.S. Statistical Evidence on the Role of Energy Cooperatives for the Energy Transition in European Countries. *Sustainability* **2018**, *10*, 3339. [CrossRef]
186. Grudziński, Z. Konkurencyjność paliw w wytwarzaniu energii elektrycznej (Competitiveness of fuels in electricity generation). *Energy Policy J.* **2013**, *6*, 87–105. Available online: https://se.min-pan.krakow.pl/publikacje/13_06zg_pe_z.pdf (accessed on 25 April 2022).
187. European Parliament and the Council, Regulation (EU) 2019/943 of the European Parliament and of the Council. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R0943 (accessed on 22 February 2022).
188. Appunn, K. Setting the Power Price: The Merit Rrder Effect. Available online: https://www.cleanenergywire.org/factsheets/setting-power-price-merit-order-effect (accessed on 22 February 2022).
189. Loumakis, S.; Giannini, E.; Maroulis, Z. Merit Order Effect Modeling: The Case of the Hellenic Electricity Market. *Energies* **2019**, *12*, 3869. [CrossRef]
190. Korkmaz, O.; Önöz, B. Modelling the Potential Impacts of Nuclear Energy and Renewables in the Turkish Energy System. *Energies* **2022**, *15*, 1392. [CrossRef]
191. What's Next after Coal? RES Potential in Poland. Raport. Instrat.pl. Available online: https://instrat.pl/wp-content/uploads/2021/06/Instrat-What-next-after-coal-v.1.2.pdf (accessed on 3 May 2022).
192. Brodny, J.; Tutak, M.; Saki, S.A. Forecasting the Structure of Energy Production from Renewable Energy Sources and Biofuels in Poland. *Energies* **2020**, *13*, 2539. [CrossRef]
193. Przybylska-Cząstkiewicz, M. The legal conditions for the development of Renewable Energy in Poland after 2015. *Energy Policy J.* **2017**, *20*, 115–116. Available online: https://epj.min-pan.krakow.pl/The-legal-conditions-for-the-development-of-Renewable-Energy-nin-Poland-after-2015,96161,0,2.html (accessed on 3 May 2022).

194. Gawlikowska-Fyk, A. Po 2025 r. Węgiel Będzie Wychodził Z Polskiego Systemu Energetycznego Falami (After 2025, Coal Will Come Out of the Polish Energy System in Waves). Available online: https://www.forum-energii.eu/pl/blog/luka-weglowa-2025 (accessed on 22 February 2022).
195. Zamasz, K. *Efektywność Ekonomiczna Przedsiębiorstwa Energetycznego W Warunkach Wprowadzenia Rynku Mocy (Economic Efficiency of an Energy Company in the Conditions of Introducing the Capacity Market)*; Wydawnictwo Naukowe PWN: Warszawa, Poland, 2015; ISBN 9788301183783.

energies

Article

Controlling in the Process of Development of the Energy and Heating Sector Based on Research of Enterprises Operating in Poland

Janusz Nesterak [1,*], Marta Kołodziej-Hajdo [2] and Michał J. Kowalski [3,*]

[1] Department of Economics and Organization of Enterprises, Cracow University of Economics, Rakowicka St. 27, 31-510 Cracow, Poland
[2] Department of Business Management, AGH University of Science and Technology in Krakow, ul. Mickiewicza 30, 30-059 Cracow, Poland
[3] Department of Management Systems and Organizational Development, Wroclaw University of Science and Technology, ul. M.Smoluchowskiego 25, 50-372 Wroclaw, Poland
* Correspondence: nesterak@uek.krakow.pl (J.N.); michal.kowalski@pwr.edu.pl (M.J.K.)

Abstract: Enterprises operating in the energy and heating (E&H) sector play a particularly important role in the economy of each country. At the same time, the conditions in which they currently operate mean that the managers of these organizations have many decision-making problems that they have to deal with. They can be supported by the introduction of well-functioning controlling. This forces scientists to conduct extended research aimed at determining the current and future directions of development of controlling in E&H sector enterprises. At the moment, this is not a frequent field of research exploration. The area of research concerns issues related to the use of controlling in E&H sector enterprises. The objective of this paper is to present the results of the research obtaining knowledge on to what extent companies in the energy and heating sector use controlling tools helping them to increase efficiency of enterprises and effectiveness of the decisions made by managers. The scientific problem is looking for a way in which controlling can increase the efficiency of enterprises in the E&H sector and how it can improve the effectiveness of decisions made by managers. The general conclusion of the research is that it seems necessary to strengthen the role of controlling aimed at its transformation from reporting controlling to management controlling. In view of the challenges of the global economy related to the energy crisis, controlling should be used to a greater extent in the E&H industry to increase the efficiency of basic processes and to effectively implement modern management tools.

Keywords: controlling; controlling tools; energy sector; energy and heating; E&H

Citation: Nesterak, J.; Kołodziej-Hajdo, M.; Kowalski, M.J. Controlling in the Process of Development of the Energy and Heating Sector Based on Research of Enterprises Operating in Poland. *Energies* **2023**, *16*, 773. https://doi.org/10.3390/en16020773

Academic Editor: Seung-Hoon Yoo

Received: 30 November 2022
Revised: 3 January 2023
Accepted: 5 January 2023
Published: 9 January 2023

1. Introduction

Increasingly, economists are of the opinion that maximizing shareholder returns should not be the main goal of companies, given the complex environment in which they operate and the interactions that exist with various stakeholders. Maximizing the positive impact of enterprises on stakeholders is a new approach that contributes to the metamorphosis of business strategies of enterprises in various fields, especially those that generate negative social and environmental expansions, such as enterprises in the energy and heating sector (E&H) [1,2].

The increase in energy demand, the level of its consumption, climate change caused by economic and social development, limited resources, and the political situation in the world brought the recognition of the strategic importance of the companies from the E&H sector. This is also reflected in specific legal regulations and instruments regulating the activities of enterprises in this sector in the EU. The economic development of countries depends on access to energy. Looking at it through the prism of numbers, it should be stated that over the period 2010–2020, the global demand for electricity increased from 64.4 thousand PJ (petajoule) up to 82.0 thousand PJ, or 27.3% over eleven years. In Poland, the trend was also upward. Electricity consumption in Poland in 2010 amounted to 427 PJ, and in 2020 it was 494 PJ, which is 15.7% more. As for heat energy, global consumption increased from 11.5 thousand PJ in 2010 to 12.9 thousand PJ in 2020, so by 12.2%. During this period, Poland saw a decrease in demand from 274 PJ in 2010 to 235 PJ in 2020 (a change of −14.2%).

The energy sector is not uniform. It consists of companies that constitute the elements of value chain of energy supplied to the end user. In addition, the characteristics of the energy market determine its dissimilarity in comparison with traditional commodity markets, as well as with the financial market [3,4]. From the institutional side, the electricity market in 2020 in Poland was dominated by the three largest entities (PGE Polska Grupa Energetyczna S.A., ENEA S.A., TAURON Polska Energia S.A.), which accounted for approximately 62% of electricity production [5]. In the case of thermal energy production, the market is more diversified. In Poland, at the end of 2020, there were 387 companies operating on the regulated heat market that held concessions for the production, transmission and distribution as well as heat trading [6].

Energy companies, while conducting business activity, are also obliged to ensure the continuity of energy supplies, while being supervised by governments. They are also subject to other systemic regulations at national and international levels. Energy sector companies are important for the economy because, on the one hand, they are obliged to ensure energy security, and on the other hand, they can lead to energy poverty, because the increase in energy prices directly affects consumers' access to energy [7,8].

On the one hand, companies operating in the E&H sector play a particularly important role in the economy of each country; on the other hand, the conditions in which these entities currently operate mean that the managers of these organizations have many decision-making problems they have to deal with. The solution is to introduce well-functioning controlling to these enterprises, which supports managers in making the right decisions. This forces scientists to conduct extended research aimed at determining the current and future directions of development of controlling in enterprises of the energy sector [9,10]. At the moment the vast majority of authors focus only on selected aspects of controlling, its instruments, or the process of implementation in enterprises of the E&H sector. Therefore, the area of research presented in this paper concerns issues related to the use of controlling in E&H sector enterprises.

The objective of this paper is to present the results of the research obtaining knowledge to what extent companies in the Energy and Heating sector use controlling tools helping them to increase efficiency of enterprises and effectiveness of the decisions made by managers.

The scientific problem is looking for a way in which controlling can increase the efficiency of enterprises in the E&H sector and how it can improve the effectiveness of decisions made by managers.

The research presented in this paper has been discussed in six parts. After the Section 1, Section 2.1 presents a literature review on the concept of controlling and its role in an enterprise management. Section 2.2 elaborates on the current scientific achievements in the area of research on the use of controlling in E&H sector enterprises. Section 3 discusses the applied research procedure and data sources. The results of the research are presented in Section 4. Finally, in Section 5, a discussion and conclusions from the conducted research are formulated.

2. Theoretical Framework

2.1. Review of the Research in the Field of Controlling

The concept of controlling does not have a uniform definition in the world literature. Different schools of thought around the world have different views, and numerous authorities in the field of management indicate helplessness in trying to organize this concept. Preissler rightly states that "everyone has their own ideas about what controlling means or should mean, only that everyone thinks something different" [11]. The multiplicity of definitions is also caused by the use of controlling in many different enterprises with different organizational or financial situations. The fact that controlling may concern many functional areas also affects the multitude of concepts. One of the reasons for many different theories may be the ambiguity of the English word "to control".

The Americans and Germans had the greatest influence on shaping the term controlling. The American approach to controlling assigns it the task of monitoring current results and constantly comparing them to planned assumptions, as well as forecasting and providing managers with various information that can serve the implementation of the company's goals. For this reason, the American controller is more identified with the finance and accounting department, and his duties are similar to those of the European chief accountant. Controlling plays an advisory role in the management process. For German scientists, controlling is a more comprehensive process that includes a wide range of instruments for managing and controlling the company's finances, while the controller's attention is focused on all departments of the company. Controlling not only supports the functions of the management process, but even creates them; hence, it can be said that it is a management system. The differences between these two fundamental approaches to controlling are presented in Table 1.

Table 1. Controlling functions according to the German and American schools.

Functions	Germany				USA			
	Controlling				Management Control (Controllership)			
Controlling Functions	**Horvath**	**Kupper**	**Vollmuth**	**Weber**	**Anthony**	**Belkaoui**	**Horngren**	**Kaplan**
Information flow	T	T	T	W/T	P	P	P/T	P
Planning	T	T	T	W/T	P	P	P	W
Control	T	T	T	W/T	P	P	P	W
Leading a team	-	T	T	W/T	W	W	P	W
Organization	-	T	T	W/T	W	W	T	W
Coordination	G	G	G	G	G	G	G	G

W—Function support, P—Taking over some functions, T—Creating a function, G—Depth of a function; Source: own elaboration based on: [12–19].

In the literature on the subject, controlling is understood ambiguously as: a philosophy [20–22], system [23–25], management method [26,27], or management tool [28–31]. It is associated with management systems and perceived as "managerial control" [32–34], or as "management control and accounting" [35–37]. Many scientists believe that the idea of controlling is now also expressed in management accounting [38] and [23] (p. 19). More and more frequently among researchers of the subject, the concept of controlling is sometimes called performance management [39–43]. The multitude of definitions, terms and interpretations indicate various areas and functions of controlling, presenting different ways of understanding it both by management theoreticians and practitioners. Research [44–47] presents detailed characteristics of controlling, its tasks, possible competencies and importance for the management system.

Understanding controlling as a tool to support managers determines its positive features, among which are: lowering costs, increasing profits, increasing work efficiency, and developing effective strategies and structures that facilitate the decision-making process by improving the information system or profitability analysis in various functional areas of the company [48].

The concept of controlling in its contemporary meaning was created in German countries and it is perceived as a subsystem supporting organization management [23]. Similarly, it is characterized as support for planning and coordination subsystems [49], or as coordination of the management system in terms of solving various types of decision-making tasks [50].

In his research, Mocanu states that controlling is an important method supporting management, it is one of the most frequently used management methods, and it is associated with a relatively large polemic related to its different perceptions [51]. The issue of controlling, due to its high applicability, is often taken up in scientific research. The works carried out by foreign and Polish scientists concern enterprises with various types of activity and from various sectors of the economy. Research conducted by Abdel-Kader and Luther [52] seeks to find out why companies adopt different practices in the field of management accounting and what the process of change in this area looks like [53]. There are also studies on the impact of variously understood managerial control strategies on the financial results of the surveyed organizations [54–61]. Schäffer and Binder present extensive considerations pointing to the development and use of management accounting and management control research in German-speaking countries [62].

Research on the use of controlling in the economy is conducted by many scientists from various foreign universities. The leaders are mainly scientists from research centres in Germany and the USA, conducting multidimensional research on enterprises using controlling [63–71]. The ICV (Controller-Verein e.V.—Wörthsee, Germany), founded in 1975, is of great importance for expanding knowledge on controlling solutions in the economy, which prepares numerous reports containing guidelines for controlling [72]. Extensive information on the development of controlling tools in the practice of German enterprises can be obtained on numerous Internet portals [73–76]. In Poland, the issue of controlling is a field of exploration pursued by many scientists. These studies are conducted mainly at the Cracow University of Economics, the Wrocław University of Economics, and the Wrocław University of Technology, with the support of scientists from other academic centres in Poland [77–88].

2.2. Controlling in Companies from the Energy and Heating Sector

Scientific considerations over the last few decades also concern the use of controlling in management within the energy sector enterprises. However, their number is relatively small, compared to the research on typically productive sectors of the economy. In manufacturing enterprises, a distinction is usually made between the primary activity related to the production of specific products and services and the auxiliary activity, the primary task of which is to support the core activity. However, the organization of manufacturing processes in energy sector enterprises is more complicated and, therefore, model controlling solutions are significantly diversified, from the method supporting management [89,90] to the implementation of its selected tools [91].

Scientific considerations regarding the energy sector indicate that Polish enterprises are often characterized by a management approach based on management accounting and budgeting. They use traditional tools in the form of budgets and financial evaluation indicators more often than more advanced controlling instruments [92–95]. A common controlling tool, implemented in practice, are models of systematic cost accounting, the implementation of which is to help in providing relevant and useful information about the costs of the company's activity [96]. In Polish research, we will also find references to the possibility of using problem-based cost accounting in energy sector enterprises, such as ecology cost accounting [97] or quality cost accounting [98]. An analogy can also be found in scientific research conducted on the example of Slovak enterprises, also from the energy sector [99].

The increase in the demand for information on the costs of energy production and transmission reported by the management staff, and on the other hand, the growing complexity of the processes of supplying individual types of energy, the significant diversity of energy consumers and products, and the increase in the share of indirect costs, became the basis for the development of management accounting instruments used in enterprises of the energy sector, especially in relation to activity-based costing [100–104].

As indicated by the researchers of the subject, companies from the energy sector are also looking for more advanced controlling tools that respond to the new approach to management—management by value. This idea considers the process of creating company value in terms of activities. According to this concept, energy company is as a whole composed of processes and activities aimed at creating value. Few studies in this area in the energy sector indicate that the integration of activity-based costing and the EVA method increases the effectiveness of enterprise management. The combination of these methods makes it possible to identify activities that reduce a company value, which should be modified or eliminated [103,105,106].

In the literature on the subject, there are also studies indicating that limited energy resources and energy security concerns in relation to alternative energy sources prompt the use of product life cycle analysis (LCA) to analyse sensitivity and compare the level of costs for different energy sources. The research points out that the concept of a product life cycle management (LCM) aims to minimize the environmental and socio-economic burdens associated with the product throughout its life cycle. It is emphasized that one of the directions of development of controlling in the energy sector should be the use of this tool by investors and decision makers in the process of making decisions regarding sustainable development [107–109].

Additionally, of interest are the studies indicating the potential of personnel controlling and the system of human capital valuation indicators in energy enterprises [45]. Some studies emphasize the importance of financial controlling and its impact on the results and efficiency of operations [110], or the possibility of using the balanced scorecard (BSC) as an instrument of strategic controlling, which can effectively support the management processes of a company operating in the E&H industry [111].

Few studies in the energy sector include: verification of the levels of use and use of BSC, the impact of individual characteristics, the most commonly used metrics and the characteristics of its effective implementation. Despite the widespread use of this instrument in many sectors of the economy, as scientific considerations show, it is not a popular controlling instrument in energy enterprises. The authors point to the need to implement BSC in these entities, for example through benchmarking on other industries where BSC was used, which should lead to faster and better results in the energy sector [112,113].

In the processes supporting project management in energy enterprises, real and adequate use should be made of project controlling [82]. The subject of consideration of researchers is also the use of controlling from the conceptual and organizational side in the process of restructuring enterprises from the energy sector [89,114–116].

Due to the nature of the E&H sector, scientists pay attention to another research area, which is the scope and effectiveness of implementing operational tools and strategic controlling in energy companies towards sustainable development and corporate social responsibility [117].

In recent years, the field of exploration has been the practice of management accounting in the field of obtaining environmental information for managers, the so-called environmental management accounting [118,119]. Many researchers [120,121] draw attention to the use of environmental reporting, with particular emphasis on the energy sector, asking how accounting and management systems introduced in enterprises can reduce their negative impact on sustainable development [122].

The literature on the subject also indicates the need to develop controlling tools for managing carbon dioxide emissions, not only in energy sector companies (so-called carbon accounting) [123,124].

In recent decades, we have been dealing with regulations' changes in many areas, including the energy sector, not only in Poland, but also in other countries. When talking about regulation, we mean widely existing (and sometimes emerging) law, other legal requirements, standards and generally recognized guidelines. Currently, scientific considerations indicate the need to conduct theoretical and empirical research in the field of controlling, management accounting in the area of regulation to which the energy system is subject. Many of these regulatory changes come with disclosure and transparency requirements. So, there is a need to test them causally, not just to document it [125].

Research conducted by Kowalewski and Lelusz [126] showed that, in the opinion of managers, often the main reason for implementing controlling in an enterprise from the energy sector is the need to systematize planning and analyses. However, the main barrier to its implementation is the insufficient knowledge of employees on this subject. According to the managers, the most important positive effects of the implementation of controlling in the E&H sector are: the organization of the division of tasks and goals to be achieved in individual organizational units as well as the increase in the professionalism of employees. The research also looks for factors determining the success of the implementation of controlling in companies from the energy sector [127].

Due to the strategic nature of this sector for the economy, E&H is subject to many legal regulations, indicated in the Energy Law [128]. The obligations of companies in this sector include the preparation of a number of industry reports indicated by the Energy Regulatory Office. Reporting obligations are also imposed by the Accounting Act [129], tax laws or requirements of other public and local government institutions. This applies to reporting not only financial data, but also qualitative and non-financial data. This multi-dimensional reporting system requires ordering and synchronization, which is ensured by well-implemented and updated reporting controlling. Hence, in the further part of the work, the results of the original research presenting the current state of the use of controlling in enterprises of the energy and heating sector in Poland are presented.

3. Data and Descriptive Statistics

Research Procedure and Data

The research procedure was adapted to the research objectives of this paper.

In the years 2013–2022, the research was conducted with the aim to determine the state of maturity of the use of controlling in enterprises operating in Poland. In the empirical research, a non-probability method of sampling (purposive sampling) was used to enable obtaining the results that were as representative as possible for the E&H registered companies. E&H firms from the companies register databases were approached. The respondents were the management representatives, including both the top management level, as well as directors or operational managers and controllers of E&H companies. The respondents were mainly employees who understood the problems posed in the research survey.

The surveys were carried out using a business intelligence IT system called Business Navigator [130] by Archman sp. z o.o. from Krakow and the Google survey system [131]. The Business Navigator system has a survey module that supports large-scale research and enables the presentation of results in any layout. Its key functionalities include: fully independent user-defined surveys and directing them to selected respondents; defining serial surveys, created and sent automatically by the system after previously defining the sending parameters; and managing access to the results for selected people. The survey was initially prepared in a spreadsheet and then transposed to the Business Navigator IT system and the Google survey system. The next step was to register the respondent's e-mail address, after obtaining his consent to participate in the study. From the IT system, the questionnaire was directly and automatically sent by e-mail to the respondent with a request to complete it. The time of starting work on the survey was recorded in the system, thanks to which it was possible to obtain information about the number of survey participants on an ongoing basis. The respondent was able to stop filling in the survey at any time, save the results, and return to it at a convenient time. After completing the questionnaire, the respondent received an automatic e-mail informing him that sending the questionnaire was successful. As a token of gratitude for their time, the respondents received an electronic version of the monograph entitled "Controlling. Assessment System of Performance Responsibility Centres." [132].

First, the questionnaire was sent to a selected group of 30 respondents (pilot studies), people who worked in controlling positions. They were asked to complete the questionnaire and indicate their comments, both substantive and technical, regarding the transparency and understanding of the questionnaire. The purpose of such action was the need to verify the research tool in such a way that it was detailed on the one hand, but on the other hand did not lead to its negative reception by the respondents. The collected comments were used to develop the second version of the questionnaire, slightly reduced in size, which was sent to 884 respondents who declared their willingness to participate in the research. The database of potential respondents was developed on the basis of initial interviews with employees of the managerial level and those employed in the financial and controlling departments of organizations operating in Poland. A fully completed questionnaire was submitted by 289 respondents (32.7% of the total research frame). A total of 595 (67.3%) surveys were not returned, with 195 (22.0%) respondents starting surveys but not completing them. Some of the respondents who did not complete the questionnaire indicated that after reading the detailed questions, they were not able to answer the questions in a professional and reliable way. They argued that they have a lack of knowledge on the subject of the conducted research.

The survey consisted of six thematic areas of various volumes. In addition, in order to obtain knowledge about the respondent, a detailed specification about them and the company they represent was included. In the survey, it was also decided to use the formula of open questions, allowing the respondents to comment more extensively on specific problems. The commentaries supplemented the answers with valuable—from the research point of view—opinions of people completing the survey.

This publication presents the results of research conducted in the areas of: organization of controlling functions, accounting recording solutions, cost accounting and cost management tools, management reporting and budgeting. The survey consisted of 103 questions, the vast majority of which were closed questions, and the respondents could add comments to their answers each time. The presented results include selected questions considered important in the course of the conducted analyses.

In the first step, the collected empirical material was analysed. The aim of the research was to analyse the controlling solutions used in companies in the energy and heating industry against the background of solutions used in enterprises of other industries. The analysis began with the presentation of the research sample. The collected empirical material covering 289 companies operating in Poland was presented, including 51 entities included in the energy and heating (E&H) industry. It should be noted that only the binding answers provided by the respondents were analysed. Missing answers and or "I do not know" answers were omitted. The energy and heating sector companies were characterized against the background of other companies (Others). Then, selected areas of controlling were analysed, looking for features characteristic of solutions used in energy and heating.

The empirical material was analysed and statistically inferred. The analyses were conducted primarily with the use of contingency tables as well as multiple-response and dichotomy tables; the descriptive statistics of defined variables were inspected and tests concerning the analysis of variance were performed. The analysis of the relationship between the variables was tested with Pearson's chi2 and maximum likelihood chi2 statistics, taking into account Yates' corrections for lower expected numbers. In addition, the assessment of the strength of the relationship between the variables was identified by Pearson's convergence coefficient and Spearman's rank correlation coefficient.

4. Empirical Framework

4.1. Characteristics of Companies in the Energy and Heating Industry

The analysed sample included companies with various characteristics. The identified size classes of entities were similar in terms of numbers: large companies—40%, medium-sized companies—29%, and small companies—31%. The sample was dominated by entities with over 15 years of experience on the market, as mature companies constituted 65% of all respondents. Companies with dominant production activity (42%) were represented similarly to companies with dominant service activity (46%), while companies with dominant commercial activity represented 12% of the total. Most of the analysed entities operated in conditions of high competition (45%) and offered specialist products (57%), acting for the mass client (75%).

E&H companies accounted for 18% of the analysed sample. Table 2 presents the characteristics of the sample broken down by the E&H sector and other entities. Companies from the E&H industry did not differ from others in terms of size and time of operation on the market, as well as in terms of the subject of activity. The homogeneity of these features in the two surveyed groups is important from the point of view of the analysis of controlling solutions observed in the E&H sector against the background of the entire sample. E&H companies in the analysed sample operated in conditions of low and medium competition much more often than in the Others group. This relationship was clear and observed at any low level of confidence. Similarly clear differences were observed for the dominant capital feature. E&H companies in the analysed sample definitely more often represented entities with dominant public capital. There were also surpluses of the observed frequencies over the expected ones for offering a mass product for both narrow and mass customers, with the statistics confirming the significance of this relationship for $0.05 < p < 0.1$.

4.2. Organization of the Controlling Function in the Energy and Heating Industry

The results of the analyses concerning the organization of the controlling function are presented in Table 3. The vast majority of the analysed E&H companies distinguished the controlling function in the organizational structure. 84% of the analysed entities declared institutional separation of this function. This share is definitely higher than in the case of other companies (58%) and the entire sample (62%). It was observed that E&H companies form controlling structures. The need to use controlling tasks seems to be present in the E&H industry, regardless of the size and time of operation of the entity on the market. Among the eight companies in which the controlling unit was not separated, there were mainly entities of medium size and average experience in the market; in three of them; the performance of controlling tasks was declared in a non-institutional form, by assigning tasks to other organizational units; and in three companies, the performance of the function was declared by an outsourced service. It is noteworthy that the implementation of controlling tasks in the E&H industry generally requires the creation of complex multi-station structures. The functioning of such structures was declared by as many as 51% of the surveyed companies and 40% of multi-position structures; only in 9% of the cases was it declared that the controlling task was handled by a single position separated in the organizational structure.

Table 2. Features of the research sample.

Panel A: Analysis Results in Two-Way Tables													
Industry/Feature		**Company Size**				**Period of Operation**				**Competition**			
		Big	**Medium**	**Small**	**Total**	**Mature**	**Medium**	**Young**	**Total**	**Big**	**Medium**	**Small**	**Total**
E&H	Count A	25.0	15.0	11.0	51	36.0	13.0	2.0	51	9.0	22.0	20.0	51
	Expected count B	20.6	14.6	15.7	51	33.4	13.9	3.7	51	22.9	18.5	9.5	51
	A-B	4.4	0.4	−4.7	0	2.6	−0.9	−1.7	0	−13.9	3.5	10.5	0
Others	Count A	92.0	68.0	78.0	238	153.0	66.0	19.0	238	121.0	83.0	34.0	238
	Expected count B	96.4	68.4	73.3	238	155.6	65.1	17.3	238	107.1	86.5	44.5	238
	A-B	−4.4	−0.4	4.7	0	−2.6	0.9	1.7	0	13.9	−3.5	−10.5	0
Total	Count A	117	83	89	289	189	79	21	289	130	105	54	289
Panel B: Statistics													
Pearson's chi-squared test ($\chi 2$)		2.836	$p = 0.242$			1.285	$p = 0.525$			25.046	$p = 0.000$		
Maximum-likelihood chi-squared		2.941	$p = 0.229$			1.436	$p = 0.487$			24.933	$p = 0.000$		
Phi coefficient (φ)		0.099				0.067				0.294			
Pearson's contingency coefficient (C)		0.098				0.066				0.282			
Spearman rank correlation coefficient (ρ)		−0.0484	$p = 0.411$			−0.057	$p = 0.332$			0.0658	$p = 0.267$		

Panel A: analysis results in two-way tables													
Industry/Feature		Product–market relationship					Dominant capital			Dominant type of activity			
		mass product, many customers	specialized product, many customers	specialized product, few customers	mass product, few customers	Total	Public	Private	Total	Production	Trade	Services	Total
E&H	Count A	22.0	16.0	8.0	5.0	51	21.0	30.0	51	22.0	10.0	19.0	51
	Expected count B	19.8	18.4	10.9	1.9	51	14.5	36.5	51	21.2	6.2	23.6	51
	A-B	2.2	−2.4	−2.9	3.1	0	6.5	−6.5	0	0.8	3.8	−4.6	0

Table 2. *Cont.*

Panel A: Analysis Results in Two-Way Tables													
Industry/Feature		**Company Size**				**Period of Operation**				**Competition**			
		Big	**Medium**	**Small**	**Total**	**Mature**	**Medium**	**Young**	**Total**	**Big**	**Medium**	**Small**	**Total**
Others	Count A	90.0	88.0	54.0	6.0	238	61.0	177.0	238	98.0	25.0	115.0	238
	Expected count B	92.2	85.6	51.1	9.1	238	67.5	170.5	238	98.8	28.8	110.4	238
	A-B	−2.2	2.4	2,9	−3.1	0	−6.5	6.5	0	−0.8	−3.8	4.6	0
Total	Count A	112	104	62	11	289	82	207	289	120	35	134	289
Panel B: Statistics													
Pearson's chi-squared test ($\chi 2$)		7.486	p = 0.057				4.994	p = 0.025		4.021	p = 0.133		
Maximum-likelihood chi-squared		6.234	p = 0.100				4.725	p = 0.029		3.732	p = 0.154		
Phi coefficient (φ)		0.160					−0.131			0.117			
Pearson's contingency coefficient (C)		0.158					0.130			0.117			
Spearman rank correlation coefficient (ρ)		−0.0138	p = 0.814				−0.131	p = 0.025		−0.054	p = 0.354		

Table 3. Organization of the controlling function in the surveyed entities.

Panel A: Analysis Results in Two-Way Tables														
Industry/Feature		**Controlling Cell**			**Type of the Cell**			**Place in the Structure**			**Dependence**			
		No	**Yes**	**Total**	**Single-Position**	**Multi-Position**	**Total**	**Line**	**Staff**	**Total**	**Manag-ement**	**Director of Finance**	**Chief Ac-countant**	**Total**
E&H	Count A	8.0	43.0	51	4.0	40.0	44	38.0	13.0	51	23.0	21.0	7.0	51
	Expected count B	19.1	31.9	51	7.8	36.2	44	30.7	20.3	51	21.3	27.1	2.7	51
	A-B	−11.1	11.1	0	−3.8	3.8	0	7.3	−7.3	0	1.8	−6.1	4.3	0
Others	Count A	96.0	130.0	226	29.0	112.0	141	83.0	67.0	150	61.0	77.0	3.0	141
	Expected count B	84.9	141.1	226	25.2	115.8	141	90.3	59.7	150	58.8	74.9	7.3	141
	A-B	11.1	−11.1	0	3.8	−3.8	0	−7.3	7.3	0	2.3	2.1	−4.3	0
Total	Count A	104	173	277	33	152	185	121	80	201	80	102	10	192
Panel B: Statistics														
Pearson's chi-squared test (χ2)		12,737	$p = 0.000$		3.013	$p = 0.082$		5.841	$p = 0.015$		10.217	$p = 0.006$		
Maximum-likelihood chi-squared		14,153	$p = 0.000$		3.391	$p = 0.065$		6.087	$p = 0.013$		8.750	$p = 0.012$		
Phi coefficient (φ)		0.214			0.127			−0.17			0.230			
Pearson's contingency coefficient (C)		0.209			0.126			0.168			0.224			
Spearman rank correlation coefficient (ρ)		0.214	$p = 0.000$		0.127	$p = 0.083$		−0.170	$p = 0.015$		0.108	$p = 0.135$		

Source: own study.

The results regarding the location of controlling tasks in the organizational structure seem surprising. Three out of four analysed companies in the E&H industry distinguish the controlling unit on the line position as one of the company's functions. The results of the conducted analyses clearly indicate that this feature distinguishes the analysed E&H companies from the other analysed entities. The differences are significant and their statistical significance has been clearly confirmed. The results are surprising, because modern controlling tasks seem to be staff orientation in the organizational structure, which was recorded only in 25% of E&H companies, compared to 55% in other companies, taking into account that a significant part of them does not distinguish controlling structures at all.

Statistical analysis shows that the direct subordination of controlling structures to the organizational structure is also a feature that distinguishes E&H companies from others. E&H companies more often than other surveyed entities subordinate their controlling unit to chief accountants and directly to the management board. Significantly less often, however, it is subordinated to the financial director. The significance of these differences in this area between the studied E&H entities and Others was confirmed statistically at a low level of confidence. This relationship seems to be worth mentioning, as it indicates that the controlling unit very often supports the reported tasks assigned to accounting departments. An interesting analysis would also be supplementing the applications with verification of how often the position of CFO is separated in E&H companies.

4.3. Accounting Records of Economic Events

Table 4 presents the results regarding the scope of separating the centres of responsibility. 75% of the surveyed companies from the E&H sector indicated that they create responsibility centres. This result is higher than in Others entities, where it is about 58%. It has been observed that E&H companies create use more responsibility centres.

Table 4. Responsibility centres in the audited entities.

Panel A: Analysis Results in Two-Way Tables							
Industry/Feature		**Responsibility Centres**			**Investment Centres**		
		NO	**YES**	**TOTAL**	**NO**	**YES**	**TOTAL**
E&H	Count A	12.0	33.0	45	29.0	22.0	51
	Expected count B	17.5	27.5	45	39.5	11.5	51
	A-B	−5.5	5.5	45	−10.5	10.5	0
Others	Count A	88.0	124.0	212	195.0	43.0	238
	Expected count B	82.5	129.5	212	184.5	53.5	238
	A-B	5.5	−5.5	0	10.5	−10.5	0
Total	Count A	100	157	257	224	65	289
Panel B: Statistics							
Pearson's chi-squared test (χ2)		3.440	$p = 0.063$		15.142	$p = 0.000$	
Maximum-likelihood chi-squared		3.586	$p = 0.058$		13.501	$p = 0.000$	
Phi coefficient (φ)		0.115			0.228		
Pearson's contingency coefficient (C)		0.114			0.223		
Spearman rank correlation coefficient (ρ)		0.115	$p = 0.064$		0.228	$p = 0.000$	

Source: own study.

The analysis of solutions in the field of recording economic events was carried out primarily in terms of the method of separating the centres of responsibility. In the survey, respondents were asked what type of responsibility centres are created, indicating the following options: department, employee, process, type of cost, type of activity, device, task/project, investment sentence and order. The question also contained an open answer, other, where the respondent could indicate any number of other centres of responsibility used.

On the basis of the answers obtained, a synthetic variable counting how many different types of responsibility centres were identified was defined. The results obtained in this regard, broken down by E&H and Others, are presented in Table 5. The results indicate that the surveyed E&H companies distinguish definitely more types of responsibility centres than other entities. The significance of these differences was confirmed by the conducted statistical analyses. Further analysis was carried out at the level of selected types of responsibility centres. Significant differences were identified primarily in relation to investment tasks. The results in this regard are presented in Table 5. Companies from the E&H sector definitely more often than other analysed entities identify centres dedicated to the implemented investments in the records system. The differences in this respect between E&H and Others are clear and reported as statistically significant at any low level of confidence. This seems to be directly related to the specificity of E&H activities, which usually require significant investments in production or network infrastructure related to energy supply.

Table 5. Number of different types of responsibility centres in the surveyed entities.

Panel A: Descriptive Statistics										
Industry	**N Valid**	**Mean**	**Trimmed Mean**	**Winsor Mean**	**Median**	**Minimum**	**Maximum**	**Q3**	**Q1**	**Standard Deviation**
E&H	37	2.730	2.636	2.676	2.000	1.000	6.000	2.000	4.000	1.427
Others	138	2.080	1.984	2.036	2.000	1.000	5.000	1.000	3.000	1.153
Panel A: Variance tests										
t	−2.890		$p = 0.004$							
quotient F	1.532		$p = 0.085$							

Source: own study.

It should be assumed that separating a given type of responsibility centre requires the organization of dedicated recording tools, most often an account segment in the records of economic events. The analysis of the tools for recording economic events presented in Table 6 shows that, in most cases, E&H companies keep records of costs directly in the financial and accounting system, without separating data relevant for management reporting outside these systems. This feature does not distinguish E&H companies from practices recorded in other entities.

The way of document circulation also distinguishes the E&H industry from the rest. Nearly 73% of the companies declared the lack of any tools supporting the circulation of documents and indicated the paper circulation of documents. This ratio is comparable to that recorded in the Others group, where it is 74%. It should be added, however, that these data were collected 5 years ago; hence, it should be assumed that the current state of use of systems supporting the circulation of documents is greater in both groups. Irrespectively, what draws attention in the obtained results is the fact that E&H companies use ERP systems directly for the circulation of documents. Both reported dependencies—more frequent use of ERP systems to handle more extensive cost accounting than observed in the Others segment and more frequent use of ERP for document circulation may be important when formulating requirements for these systems for the E&H industry.

Table 6. Accounting record tools used in the surveyed entities.

Panel A: Analysis Results in Two-Way Tables									
Industry/Function		**Document Workflow Tools**				**System of Cost Record Accounting**		
		Absence	**ERP**	**Dedicated**	**TOTAL**	**Dedicated**	**Accounting System**	**TOTAL**
E&H	Count A	32.0	10.0	2.0	44	5.0	35.0	40
	Expected count B	32.4	5.5	6.1	44	8.6	31.4	40
	A-B	−0.4	4.5	−4.1	0	−3.6	3.6	0
Others	Count A	144.0	20.0	31.0	195	47.0	154.0	201
	Expected count B	143.6	24.5	26.9	195	43.4	157.6	201
	A-B	0.4	−4.5	4.1	0	3.6	−3.6	0
Total	Count A	176	30	33	239	52	189	241
Panel B: Statistics								
Pearson's chi-squared test (χ2)		5.841	$p = 0.015$			2.335	$p = 0.126$	
Maximum-likelihood chi-squared		6.088	$p = 0.013$			2.587	$p = 0.107$	
Phi coefficient (φ)		−0.17				0.098		
Pearson's contingency coefficient (C)		0.168				0.097		
Spearman rank correlation coefficient (ρ)		−0.17	$p = 0.015$			0.098	$p = 0.127$	

Source: own study.

4.4. Cost Accounting and Cost Management Tools

Further analyses of controlling solutions focused on the applied cost accounting. The results of selected analyses are presented in Table 7. Based on the observations made, it is difficult to identify cost accounting solutions dedicated or preferred in the E&H industry. The observations made indicate that respondents from E&H pointed to the use of variable costing much less often than other market segments. The results confirm the statistical significance of these differences at any low level of significance. There was an excess of the observed numbers over the expected ones in the case of full cost accounting in E&H companies, but the analyses did not confirm that this segment differed from the others in a statistically significant way. The use of problem costing, including activity-based costing in the observed E&H group, was low and amounts to about 8%. The observed use of these cost accounts in the Others group was also low and amounts to approximately 15%. Statistical analysis, however, does not allow accepting the hypothesis that the use of these cost management tools differs significantly in both analysed groups.

Differences between the groups were noted in terms of cost accounting techniques and tools used. E&H companies more often apply tasks related to cost settlements directly to ERP systems; similar dependencies have already been identified in other areas. The use of dedicated tools (controlling systems) or even a spreadsheet for tasks related to cost settlement is observed less often in the E&H industry than in other analysed entities.

In the conducted research, the types of cost settlements were analysed. Respondents were asked both what cost settlements are performed and what are the basis for these settlements. Selected results are summarized in Tables 7 and 8. The conducted analysis showed that respondents most often indicated the use of one type of cost carrier, average 1.5, with a choice of: natural units (pcs., kg, etc.), direct costs, internally defined price lists, transfer pricing rates, agreed percentages, normative costs, person-hours according to registered working time and others with the option of indicating any other settlement bases.

Table 7. Cost accounting and cost management in the surveyed enterprises.

Panel A: Analysis Results in Two-Way Tables																				
Industry/Feature		**Variable Costing**			**Full-Absorption Costing**			**Activity-Based Costing**			**Cost Accounting Records System**				**Time Accounting**			**Margin Model**		
		No	**Yes**	**Total**	**No**	**Yes**	**Total**	**No**	**Yes**	**Total**	**Excel**	**Ded-icated**	**Accounting System**	**Total**	**No**	**Yes**	**Total**	**No**	**Yes**	**Total**
E&H	Count A	37.0	14.0	51	29.0	22.0	51	47.0	4.0	51	2.0	6.0	41.0	98	17.0	34.0	51	16.0	9.0	25
	Expected count B	26.6	24.4	51	25.2	25.8	51	45.7	5.3	51	4.1	12.0	32.9	49	33.0	18.0	51	13.7	11.3	25
	A-B	10.4	−10.4	0	3.8	−3.8	0	1.3	−1.3	0	−2.1	−6.0	8.1	49	−16.0	16.0	0	2.3	−2.3	0
Others	Count A	114.0	124.0	238	114.0	124.0	238	212.0	26.0	238	18.0	53.0	120.0	191	170.0	68.0	238	106.0	92.0	198
	Expected count B	124.4	113.6	238	117.8	120.2	238	213.3	24.7	238	15.9	47.0	128.1	191	154.0	84.0	238	108.3	89.7	198
	A-B	−10.4	10.4	0	−3.8	3.8	0	−1.3	1.3	0	2.1	6.0	−8.1	0	16.0	−16.0	0	−2.3	2.3	0
Total	Count A	151	138	289	143	146	289	259	30	289	20	59	161	289	187	102	289	122	101	223
Panel B: Statistics																				
Pearson's chi-squared test		10,228	$p = 0.001$		1.349	$p = 0.245$		0.429	$p = 0.512$		7.675	$p = 0.021$			26.689	$p = 0.000$		0.981	$p = 0.321$	
Maximum-likelihood chi-squared		10,591	$p = 0.001$		1.352	$p = 0.244$		0.457	$p = 0.499$		8.438	$p = 0.014$			25.564	$p = 0.000$		0.996	$p = 0.318$	
Phi coefficient (φ)		−0.18			−0.06			−0.03			0.178				0.303			−0.066		
Pearson's contingency coefficient (C)		0.184			0.068			0.038			0.176				0.290			0.066		
Spearman rank correlation coefficient (ρ)		−0.18	$p = 0.001$		−0.060	$p = 0.246$		−0.03	$p = 0.514$		0.176	$p = 0.006$			0.303	$p = 0.000$		−0.066	$p = 0.324$	

Source: own study.

Table 8. Number of types of billing keys used.

Panel A: Descriptive Statistics										
Industry	**N Valid**	**Mean**	**Trimmed Mean**	**Winsor Mean**	**Median**	**Minimum**	**Maximum**	**Q3**	**Q1**	**Standard Deviation**
E&H	50	1.580	1.477	1.540	1.000	1.000	4.000	2.000	0.859	1.427
Others	216	1.667	1.567	1.662	1.000	1.000	5.000	2.000	0.950	1.153
Panel A: Variance tests										
t	0.591	$p = 0.555$								
quotient F	1.222	$p = 0.408$								

Source: own study.

There were no significant differences in the number of cost carrier types used between the companies classified in the E&H and Others groups. However, differences in the frequency of use of particular types of carriers were identified. Companies in the E&H industry use time-based cost settlements more often than observed in other entities. The excess of observed observations over expected observations is significant and confirms the statistical significance of the conclusion.

There were also no differences as to the introduction of controlling reporting models for the profit and loss account in the form of a multi-block margin account. Only 36% of respondents from the E&H industry indicated that the companies they represent create this type of model, in the group of other companies, the corresponding indicator is 46%. The small number of observations recorded in this respect for E&H does not allow us to confirm the statistical significance of the observed differences.

4.5. Role and Tasks of Controlling

The scope of activities undertaken by the controlling structures created in the surveyed enterprises was also analysed. The survey indicated typical activities carried out by the controlling department, asking the respondents to indicate whether the given activities are undertaken and what percentage of time the controllers spend on their performance. The analysed tasks included: supporting strategic planning, budgeting and cost control, providing information from the environment, providing management tools, coordination of planning and control, monitoring goals, operational tasks of employees, budgets and implementation of strategic tasks, internal and external reporting, creating analyses and reports on the company's environment and internal financial statements, implementation of new and optimization of existing IT tools, support for planning and financial control, and other tasks. Selected obtained results are presented in Table 9. The obtained results allowed us to identify the relationships presented below.

The tasks of controlling in E&H companies more often than in other analysed entities concern budgeting. Budget management as a task of controllers was indicated more often in a statistically significant way in E&H companies compared to Others companies. At the same time, it was noted that respondents in E&H companies indicated that a greater percentage of controllers' working time was devoted to this task. For E&H companies, there were surpluses of the observed numbers over the expected ones in the category above 50% of working time and 25–50% of working time is devoted to budgeting and supervision over the implementation of the budget. Companies from the Others group more often spend up to 25% of their working time on this type of activity. The significance of these dependencies was confirmed at the level of $p = <10\%$, but it is not without significance here that the respondents to the questions asking for an estimate of the time spent on particular activities often did not answer or chose the answer "I do not know", as a result of which the collected material was often insufficient to carry out full inference.

Table 9. The tasks and role of controlling indicated by the respondents.

Panel A: Analysis Results in Two-Way Tables																		
Industry/Feature		**Reporting Tools**					**Budgeting**				**Operational Support**					**Decision Making**		
		Excel by Hand	**Domain System**	**Wareh-ouse**	**Excel Automat**	**Total**	**>50%**	**<25%**	**25–50%**	**Total**	**0%**	**<25%**	**25–50%**	**>50%**	**Total**	**No**	**Yes**	**Total**
E&H	Count A	17.0	14.0	9.0	8.0	48	21.0	8.0	21.0	50.0	14.0	12.0	14.0	0.0	40.0	41.0	6.0	47
	Expected count B	14.5	22.5	6.2	4.8	48	19.5	14.0	16.5	50.0	11.3	8.0	19.3	1.5	40.0	36.6	10.4	47
	A-B	2.5	−8.5	2.8	3.2	0	1.5	−6.0	4.5	0.0	2.8	4.0	−5.3	−1.5	0.0	4.4	−4.4	0
Others	Count A	55.0	98.0	22.0	16.0	191	57.0	48.0	45.0	150.0	31.0	20.0	63.0	6.0	120.0	90.0	31.0	121
	Expected count B	57.5	89.5	24.8	19.2	191	58.5	42.0	49.5	150.0	33.8	24.0	57.8	4.5	120.0	94.4	26.6	121
	A-B	−2.5	8.5	−2.8	−3.2	0	−1.5	6.0	−4.5	0.0	−2.8	−4.0	5.3	1.5	0.0	−4.4	4.4	0
Total	Count A	72	112	31	24	239	78	56	66	200	45	32	77	6	160	131	37	168
Panel B: Statistics																		
Pearson's chi-squared test (χ2)		12.737	p = 0.000				5.218	p = 0.073			7.472	p = 0.058				3.256	p = 0.071	
Maximum-likelihood chi-squared		14.153	p = 0.000				5.567	p = 0.061			8.790	p = 0.032				3.534	p = 0.060	
Phi coefficient (φ)		0.214					0.161				0.216					−0.138		
Pearson's contingency coefficient (C)		0.209					0.159				0.211					0.137		
Spearman rank correlation coefficient (ρ)		0.214	p = 0.000				0.037	p = 0.602			−0.02	p = 0.799				−0.13	p = 0.071	

Panel A: analysis results in two-way tables										
Industry/Feature		Budget management			Process management			External reporting		
		No	Yes	Total	No	Yes	Total	No	Yes	Total
E&H	Count A	20.0	31.0	51	10.0	41.0	51.0	23.0	28.0	51.0
	Expected count B	28.4	22.6	51	12.4	38.6	51.0	31.8	19.2	51.0
	A-B	−8.4	8.4	0	−2.4	2.4	0.0	−8.8	8.8	0.0
Others	Count A	141.0	97.0	238	60.0	178.0	238.0	157.0	81.0	238.0
	Expected count B	132.6	105.4	238	57.6	180.4	238.0	148.2	89.8	238.0
	A-B	8.4	−8.4	0	2.4	−2.4	0.0	8.8	−8.8	0.0
Total	Count A	161	128	289	70	219	289	180	109	289

Table 9. *Cont.*

Panel A: Analysis Results in Two-Way Tables																	
Industry/Feature	**Reporting Tools**					**Budgeting**				**Operational Support**					**Decision Making**		
	Excel by Hand	**Domain System**	**Wareh-ouse**	**Excel Automat**	**Total**	**>50%**	**<25%**	**25–50%**	**Total**	**0%**	**<25%**	**25–50%**	**>50%**	**Total**	**No**	**Yes**	**Total**
Panel B: Statistics																	
Pearson's chi-squared test (χ2)				6.828	$p = 0.008$				0.7181	$p = 0.396$				7.786		$p = 0.005$	
Maximum-likelihood chi-squared				6.796	$p = 0.009$				0.7457	$p = 0.387$				7.567		$p = 0.005$	
Phi coefficient (φ)				0.153					0.049					0.164			
Pearson's contingency coefficient (C)				0.151					0.049					0.161			
Spearman rank correlation coefficient (ρ)				0.153	$p = 0.008$				0.049	$p = 0.398$				0.164		$p = 0.005$	

Source: own study.

An observation regarding external reporting is also noteworthy. Compared to the Others segment, E&H companies more often indicated that such actions were taken by the controlling services. Differences are confirmed statistically. Their reasons should probably be sought in the obligations imposed on E&H companies related to reporting to market regulators.

In E&H companies, activities related to the direct involvement of controllers in decision-making processes or preparation of decisions were less frequently recorded. Although there were no differences in the frequency of activities related to process efficiency management, which are rarely undertaken both in the E&H and Others industries, 20% and 25% of respondents, respectively, indicated that controllers undertook this type of activity; the differences in supporting the building of operational efficiency were more visible. Controllers of E&H companies are less likely to engage in activities related to supporting the building of operational efficiency compared to the observations recorded for Others companies.

There were observed surpluses of the observed frequencies over the expected ones for the following categories: (1) analyses are not conducted and (2) up to 25% of working time is devoted to analyses, with the significance level of p = <10%. Similarly, it has been noted that E&H companies are less likely to involve controllers in decision-making processes.

Tools supporting the work of controllers were also analysed. The E&H industry is dominated by reporting based on obtaining data from ERP systems and using various tools (spreadsheets, automatically fed spreadsheets, and data warehouses) and their further processing into controlling reports. It has been observed that systems dedicated to management reporting are used less frequently in E&H companies compared to the Others segment.

4.6. Budgeting

Over 90% of the analysed E&H companies declared that they implement procedures related to budgeting. In this respect, the E&H companies performed slightly better compared to the Others group, where this ratio was 85%. However, one cannot talk about the statistical significance of these differences. Additionally, the results, related to the assessment of the business usefulness of the implemented budget processes, were somewhat surprising, indicated in the synthetic assessment made by the respondents as part of the question whether budget processes fulfil their tasks. For companies from the E&H sector, respondents more often indicated “no” and “rather no” answers compared to the choice of these answers indicated in the Others group. The results obtained in this regard are presented in Table 10.

Table 10. Implementation of budgeting processes and assessment of their usefulness.

Panel A: Analysis Results in Two-Way Tables								
Industry/Feature		**Budget is Prepared?**			**Is the Budget Fulfilling the Tasks?**		
		Yes	**No**	**Total**	**Yes or Rather Yes**	**No or Rather No**	**Total**
E&H	Count A	38.0	4.0	42	25.0	19.0	44.0
	Expected count B	36.2	5.8	42	35.3	8.7	44.0
	A-B	1.8	−1.8	0	−10.3	10.3	0.0
Others	Count A	197.0	34.0	231	153.0	25.0	178.0
	Expected count B	198.8	32.2	231	142.7	35.3	178.0
	A-B	−1.8	1.8	0	10.3	−10.3	0.0
Total	Count A	235	38	273	178	44	222
Panel B: Statistics							
Pearson's chi-squared test (χ2)		0.800	p = 0.670		18.846	p = 0.000	
Maximum-likelihood chi-squared		0.870	p = 0.647		16.431	p = 0.000	
Phi coefficient (φ)		0.054			0.291		
Pearson's contingency coefficient (C)		0.054			0.279		
Spearman rank correlation coefficient (ρ)		−0.05	p = 0.372		0.291	p = 0.000	

Source: own study.

In order to assess the reasons for this state of affairs, the occurrence of errors and deficiencies of budgetary processes most often indicated in the literature was analysed. In the questions presented to the respondents, it was verified whether they indicated the following issues:

- There is a budget, but there are no strategic goals and tasks, so we do not know where we are going; there is no connection with the strategy (involving managers in explaining, commenting on deviations from budgets).
- The budget is detached from strategic goals and tasks.
- Budgets are out of date (outdated).
- Budgets are rigid and therefore do not adjust to the current market situation (mismatched to the market situation).
- Budgets are too general (too general).
- Budgets are too detailed (too detailed).
- There is a belief that if there is a budget, it is necessary to complete all purchases, even those unjustified (priority of implementation).
- Preparation of budgets is very time-consuming (time-consuming).
- Budgets are imposed on managers in advance (imposed).
- Managers have to explain business-insignificant deviations.
- Managers prepare budgets and then fail to implement them anyway (non-compliance).

The results obtained for selected parameters are presented in Table 11.

Table 11. Budgeting problems indicated by respondents.

Panel A: Analysis Results in Two-Way Tables																				
Industry/Feature		**No Link with the Strategy**		**Outdated**		**Non-Compliance**		**Too General**		**Too Detailed**		**Priority of Implementation**		**Mismatched to the Market**		**Time-Consuming**		**Enforced**		
		No	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**Total**
E&H	Count A	46.0	5.0	38.0	13.0	45.0	6.0	48.0	3.0	39.0	12.0	38.0	13.0	38.0	13.0	36.0	15.0	42.0	9.0	51
	Expected count B	44.3	6.7	45.5	5.5	43.9	7.1	45.5	5.5	44.1	6.9	44.5	6.5	44.5	6.5	40.8	10.2	39.4	11.6	51
	A-B	1.7	−1.7	−7.5	7.5	1.1	−1.1	2.5	−2.5	−5.1	5.1	−6.5	6.5	−6.5	6.5	−4.8	4.8	2.6	−2.6	0
Others	Count A	205.0	33.0	220.0	18.0	204.0	34.0	210.0	28.0	211.0	27.0	214.0	24.0	214.0	24.0	195.0	43.0	181.0	57.0	238
	Expected count B	206.7	31.3	212.5	25.5	205.1	32.9	212.5	25.5	205.9	32.1	207.5	30.5	207.5	30.5	190.2	47.8	183.6	54.4	238
	A-B	−1.7	1.7	7.5	−7.5	−1.1	1.1	−2.5	2.5	5.1	−5.1	6.5	−6.5	6.5	−6.5	4.8	−4.8	−2.6	2.6	0
Total	Count A	251	38	258	31	249	40	258	31	250	39	252	37	252	37	231	58	223	66	289
Panel B: Statistics																				
Pearson's chi-squared test (χ2)		0.606	$p =$ 0.436	14.095	$p =$ 0.000	0.223	$p =$ 0.636	1.517	$p =$ 0.217	5.347	$p =$ 0.020	8.929	$p =$ 0.002	8.929	$p =$ 0.002	3.369	$p =$ 0.066	0.946	$p =$ 0.330	
Maximum-likelihood chi-squared		0.646	$p =$ 0.421	11.507	$p =$ 0.000	0.231	$p =$ 0.630	1.728	$p =$ 0.188	4.714	$p =$ 0.029	7.636	$p =$ 0.005	7.636	$p =$ 0.005	3.127	$p =$ 0.077	0.992	$p =$ 0.319	
Phi coefficient (φ)		−0.041		0.220		−0.021		−0.07		0.135		0.175		0.175		0.107		−0.05		
Pearson's contingency coefficient (C)		0.045		0.215		0.027		0.072		0.134		0.173		0.173		0.107		0.057		
Spearman rank correlation coefficient (ρ)		−0.041	$p =$ 0.437	0.220	$p =$ 0.000	−0.02	$p =$ 0.637	−0.07	$p =$ 0.219	0.135	$p =$ 0.020	0.175	$p =$ 0.002	0.175	$p =$ 0.002	0.107	$p =$ 0.066	−0.05	$p =$ 0.332	

The budget processes implemented in E&H companies do not seem to generate problems related to the mismatch with the company's strategy. However, the situation related to the adequacy of budgets to the changing market situation looks different. E&H respondents in 25% of cases indicated that budgets are mismatched to the current market situation. In the Other group, 10% of respondents indicated a similar mismatch. The conducted analyses confirmed that the mismatch between budgets and the market situation is higher than in companies from the Others sector. Similar results were obtained in the case of the point concerning the lack of flexibility of budgets, which means that they do not adjust to the current market situation. E&H respondents more often pointed to this problem in relation to the Others sector, which confirms the statistical significance of these differences.

The obtained results indicate that the applied budgetary procedures are assessed by the respondents as too detailed and excessively laborious, with an excessive regime of compliance with budget assumptions that does not take into account the current situation. Respondents indicated the occurrence of these problems more often in E&H companies, compared to the responses recorded for the Others group. The differences were confirmed as statistically significant.

Due to the identified challenges of budgeting processes, the scope of created budgets was analysed. Respondents were asked what elements the budget contains, and to indicate those that are present in the company. The question distinguishes: pro-forma balance sheet, depreciation budget, investment budget, direct costs budget, overhead budget, sales budget, salary budget, pro-forma cash flow statement, consolidated budget of costs and revenues in the management layout, consolidated budget in the accounting layout profit and loss account (the so-called pro-forma profit and loss account), budgets of individual organizational units, budgets of individual accounting accounts, quantity budgets (kg, items, m), budgets for individual products, and budgets for individual contractors. Then, how many of the indicated budget elements were used in a given entity was counted. The results obtained for the synthetic variable defined in this way (budget complexity) are presented in Table 12. E&H companies showed a higher content of budgets. The presence of 8 items was most often indicated (average 7.1), while in the Others group, a median of 6 and an average of 6.0 were noted.

Table 12. Budget complexity.

Panel A: Descriptive Statistics										
Industry	**N Valid**	**Mean**	**Trimmed Mean**	**Winsor Mean**	**Median**	**Minimum**	**Maximum**	**Q3**	**Q1**	**Standard Deviation**
E&H	51	7.098	7.133	7.118	8.000	1.000	15.000	4.000	10.000	3.700
Others	192	5.984	6.017	5.964	6.000	1.000	15.000	4.000	8.000	2.961
Panel A: Variance tests										
t	−2.259	*p*	0.025							
quotient F	1.561	*p*	0.035							

Source: own study.

Selected other characteristics of budgeting processes are presented in Table 13 E&H companies used fixed, non-updated annual budgets more often than the Others group, and they used rolling budgets less often, but the significance of these differences was not confirmed with a sufficient level of confidence. There were no differences in the central mode of budgeting or the influence of the manager on budgets when comparing the results for the E&H and Others groups. In turn, clear differences were observed in the processes of budget implementation. No differences were identified in the frequency of reporting deviations, while E&H companies indicate that they are less likely to involve managers in explaining them. E&H companies report the use of IT tools in budgeting more often than Others group.

Table 13. Characteristics of budgeting processes in the surveyed enterprises.

Panel A: Analysis Results in Two-Way Tables																	
Industry/Feature		**Is the Budget Updated?**				**Who is Budgeting?**			**Manager's Influence**			**IT System**			**Deviation Analysis**		
		Quarterly. Semi-Annually	**Quarterly Rolling**	**Annual not Updated**	**Total**	**Department**	**Centrally**	**Total**	**Yes**	**No**	**Total**	**Yes**	**No**	**Total**	**Yes**	**No**	**Total**
E&H	Count A	0.0	22.0	4.0	26	26.0	20.0	46.0	28.0	17.0	45	23.0	26.0	49	14.0	30.0	44
	Expected count B	2.1	21.7	2.2	26	25.3	20.7	46.0	30.6	14.4	45	17.2	31.8	49	25.6	18.4	44
	A-B	−2.1	0.3	1.8	0	0.7	−0.7	0.0	−2.6	2.6	0	5.8	−5.8	0	−11.6	11.6	0
Others	Count A	18.0	164.0	15.0	197	91.0	76.0	167.0	116.0	51.0	167	59.0	126.0	185	118.0	65.0	183
	Expected count B	15.9	164.3	16.8	197	91.7	75.3	167.0	113.4	53.6	167	64.8	120.2	185	106.4	76.6	183
	A-B	2.1	−0.3	−1.8	0	−0.7	0.7	0.0	2.6	−2.6	0	−5.8	5.8	0	11.6	−11.6	0
Total	Count A	18	186	19	223	117	96	213	144	68	212	82	152	234	132	95	227
Panel B: Statistics																	
Pearson's chi-squared test ($\chi2$)		4.008	$p = 0.134$			0.0600	$p = 0.806$		0.852	$p = 0.355$		3.853	$p = 0.049$		15.550	$p = 0.000$	
Maximum-likelihood chi-squared		5.823	$p = 0.054$			0.0601	$p = 0.806$		0.835	$p = 0.360$		3.744	$p = 0.052$		15.467	$p = 0.000$	
Phi coefficient (φ)		0.134				−0.01			0.063			−0.12			−0.26		
Pearson's contingency coefficient (C)		0.132				0.016			0.063			0.127			0.253		
Spearman rank correlation coefficient (ρ)		0.133	$p = 0.046$			−0.01	$p = 0.807$		0.063	$p = 0.358$		−0.12	$p = 0.049$		−0.26	$p = 0.000$	

Source: own study.

5. Discussion and Conclusions

The Polish energy sector is largely detached from the proven laws of economics and does not follow global development trends. This is important for the economy as it generates very high costs and strives to increase the scale of domestic funding, without introducing changes aimed at adapting to the real economy and global trends. Poland occupies the penultimate place in Europe (per capita) when it comes to obtaining funds for research and development in the field of energy. In addition, the monopolization of the energy sector supports those business models that are based on protecting the state and limiting innovation.

Gradual changes are visible in the economic area, especially in the area of implementing controlling and adjusting it to the specific needs of energy companies. A properly designed controlling system provides the management of an energy company with access to information indicating which product or service is profitable, which creates added value, and which brings losses. The database of information on the costs incurred in connection with the conducted activity enables the optimization of the use of possessed resources and the achievement of the planned goals of this sector of the economy.

Proper management of the effects of operating activities becomes a necessity, and the measurement of the effectiveness of decisions taken is an element of management focused on creating conditions for a stable improvement in economic results. Controlling contributes to supervising the stability of economic results by ensuring that their improvement is linked to the rationalization of the financing costs related to the functioning of the enterprise.

The main purpose of the conducted research was to obtain knowledge on to what extent companies in the energy and heating sector use controlling tools.

The conclusions from original empirical research are:

- The conducted research shows that controlling is an important issue for the E&H industry. Companies in the sector declare the use of controlling in business activity much more often than others, and this relationship is observed regardless of the size or period of operation of the company on the market.
- The results of the study indicate that the tasks of controlling in the E&H industry are different to those observed in other industries. A large share of reporting tasks focusing on budget management and investments is noteworthy. Research shows that controlling very often supports reporting tasks related to the processing of accounting data, which strongly supports accounting departments. This role is strongly influenced by the need to fulfil numerous reporting obligations, including those for energy market regulators. An important task of controlling in the E&H industry is reporting on investments, which is related to the specificity of the industry requiring numerous investments. The tasks of controlling in E&H companies, more often than in other analysed entities, concern budgeting. Budget management is indicated as the main task involving controlling services, and E&H companies devote much more time to this purpose than in other industries.
- Controlling tasks translate into the way the controlling is organized in E&H enterprises. Furthermore, the tasks performed are so diverse that it is necessary to expand the enterprises' organizational structures. E&H companies more often create multi-position organizational units. Examples of overly developed controlling divisions consisting of many people and positions have been observed many times. The need to use controlling tasks seems to be present in the E&H industry, regardless of the size and time of operation of the entity on the market. What is worth emphasizing is that the controlling department is most often located in the organizational structure in a linear position, which clearly distinguishes E&H from other companies. The specific and dominant solutions also include assigning the responsibility of supervision over controlling directly to the chief accountant.
- E&H's extensive reporting needs to translate into complex cost accounting systems. E&H creates more complex record systems and separates more account segments than

are used outside of this industry. There were solutions in which more than 10 account segments were used. Most often, this record, as well as cost settlements, are made directly in the accounting system. E&H companies use multiple costing, typically time-based. All this causes the information on costs to become highly complex and, as the conclusions of the conducted research show, it is not easy to report.

- The conducted research indicates that the controlling solutions are of the nature of reporting controlling, not management controlling. Research indicates that controlling tasks rarely focus on support in formulating and implementing decisions. Controllers of E&H companies are less likely to engage in activities related to supporting the building of operational efficiency compared to observations recorded for companies outside this industry. Consuming significantly more time than in other industries, the budgeting process appears to be ineffective in the light of the conducted research. Over 43% of respondents state that budgeting in E&H does not fulfil its tasks and this ratio is definitely higher in the E&H industry than in other groups of enterprises. Detailed budgeting and budgeting procedures are more extensive compared to the other groups. Preparation of one, rigid annual budget, which is not modified during the year, is very common. In most cases, the budget is prepared mainly to fulfil the indicated reporting obligations towards regulators and does not fulfil its management controlling function. This is evidenced by the rare involvement of managers in explaining deviations from budgets, which was revealed in the research.

To improve the efficiency and effectiveness of enterprises operating in the E&H sector, the authors recommend primarily:

- Strengthening the role of controlling aimed at its transformation from reporting controlling to management controlling; in view of the challenges of the global economy related to the energy crisis, controlling should be used to a greater extent in the E&H industry to increase the efficiency of basic processes and effectively implement management tools.
- Strengthening the role of the controlling department in the enterprise as a department co-creating decisions, changing its place in the organizational structure from a line position to a staff position; this raises the authority of the controlling department and it is conducive to achieving the assumed goals.
- Assigning typical reporting activities, specific to the E&H industry, regarding mandatory reporting for regulators or development funds to dedicated units; controlling departments should be relieved of these reporting tasks.
- The separation of accounting records from controlling records, because controlling for effectiveness measurement requires completely different, sometimes even variant, settlements of cost assignments; these analyses cannot and should not be carried out in accounting systems and should not affect companies' trading books. The observed solutions cause, on one hand, an increase in labour intensity on the part of accounting departments, and on the other hand, they limit access to information useful for airworthy cost and efficiency management.
- The use of cost drivers other than working time and the introduction of tools supporting the use of working time for cost settlements; additionally, reporting of the costs of unused production capacity should be introduced, which is particularly important in E&H companies.
- Simplifying and making budget processes more flexible, which can be achieved by implementing more frequently verified and rolling budgets, developed on the basis of key parameters and involving fewer employees; this will enable better use of forecasting tools, including scenario budgeting.
- Linking information from controlling systems with the process of motivating employees and making part of their remuneration dependent on the effectiveness of the tasks performed; the presented answers of respondents to questions in this area indicate great difficulties in implementing this solution, which is the result of low involvement

of the managerial staff of E&H sector enterprises and it limits benefits resulting from the analysis of controlling data.

- Increasing the emphasis on the use of modern IT tools, business intelligence, and performance management classes supporting the use of management controlling, as well as increasing interest in artificial intelligence algorithms.

Author Contributions: Conceptualization, J.N.; Methodology, J.N., M.K.-H. and M.J.K.; Software, M.J.K.; Validation, M.J.K.; Formal analysis, M.J.K.; Investigation, M.J.K.; Writing—original draft, M.K.-H.; Writing—review & editing, J.N. and M.K.-H.; Visualization, J.N.; Supervision, J.N.; Project administration, J.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by a subvention granted to the AGH University of Science and Technology in Krakow, Cracow University of Economics and Wroclaw University of Science and Technology.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available.

Conflicts of Interest: The authors declare no conflict of interest. The funder had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Pätäri, S.; Arminen, H.; Tuppura, A.; Jantunen, A. Competitive and responsible? The relationship between corporate social and financial performance in the energy sector. *Renew. Sustain. Energy Rev.* **2014**, *37*, 142–154. [CrossRef]
2. Gigauri, I. Corporate Social Responsibility and COVID-19 Pandemic Crisis: Evidence from Georgia. *Int. J. Sustain. Entrep. Corp. Soc. Responsib.* **2021**, *6*, 30–47. [CrossRef]
3. Matusiak, B.E. *Modele Biznesowe NA Zintegrowanym Rynku Energii*; Wydawnictwo Uniwersytetu Łódzkiego: Łódź, Poland, 2013; ISBN 978-83-7525-938-4.
4. Weron, A.; Weron, R. *Giełda Energii. Strategie ZarząDzania Ryzykiem*; CIRE: Wrocław, Poland, 2000; ISBN 83-913864-0-6.
5. Urząd Regulacji Energetyki. Available online: https://www.ure.gov.pl/pl/energia-elektryczna/charakterystyka-rynku/9659,2020.html (accessed on 20 October 2022).
6. Urząd Regulacji Energetyki. Available online: https://www.ure.gov.pl/pl/cieplo/charakterystyka-rynku/10165,2020.html (accessed on 20 October 2022).
7. Neacsa, A.; Panait, M.; Muresan, J.D.; Voica, M.C. Energy poverty in European Union: Assessment difficulties, effects on the quality of life, mitigation measures. some evidences from Romania. *Sustainability* **2020**, *12*, 4036. [CrossRef]
8. Druică, E.; Goschin, Z.; Ianole-Călin, R. Energy poverty and life satisfaction: Structural mechanisms and their implications. *Energies* **2019**, *12*, 3988. [CrossRef]
9. Irrek, W. *Controlling der Energiedienstleistungsunternehmen*; Josef Eul Verlag GmbH: Lohmar, Germany, 2003; ISBN 3-89936-219-5.
10. Czajor, P. *Rola RachunkowośCi ZarząDczej W ZarząDzaniu Polskimi Elektrowniami W Warunkach Liberalizacji Rynku Energii Elektrycznej*; Wydawnictwo Uniwersytetu Łódzkiego: Łódź, Poland, 2012; ISBN 978-83-7525-711-3.
11. Preißler, P. *Controlling: Lehrbuch und Intensivkurs*, 14th ed.; De Gruyter Oldenbourg: Vien, Austria, 2013; ISBN 978-3486726978.
12. Janczyk-Strzała, E. *Controlling W Przedsiębiorstwach Produkcyjnych*, 3rd ed.; CeDeWu: Warszawa, Poland, 2019; ISBN 978-83-8102-196-8.
13. Anthony, R. *Management Control Function*; Harvard Business School Press: Boston, MA, USA, 1998; ISBN 0875841848.
14. Belkaoui, A. *Handbook of Management Control Systems*; Quorum Books: New York, NY, USA, 1986; ISBN 9780899301785.
15. Horngren, C. *Management and Cost Accounting*; Prentice Hall: New Jersey, NJ, USA, 2008.
16. Kaplan, R. *Management Control System*; McGraw Hill: New York, NY, USA, 2006.
17. Kupper, H. *Controlling*; Schaffer-Poeschel: Berlin, Germany, 2005.
18. Vollmuth, H. *Controlling, Planowanie, Kontrola, Kierowanie*; Placet: Warszawa, Poland, 2007; ISBN 9788374881159.
19. Weber, J. *Wprowadzenie do controllingu*; Profit: Katowice, Poland, 2001; ISBN 83-911079-7-3.
20. Coenenberg, A.G. *Betriebswirtschaft für Führungskräfte*; Verlag Schaeffer-Poeschel: Berlin, Germany, 2006.
21. Hahn, D. Controlling—Stand und Entwicklungstendenzen unter besonderer Berücksichtigung des CIM-Konzeptes. *Rechn. EDV* **1987**, *8*, 3–39.
22. Pfohl, H. Chr. Controlling-Konzepte, "Controllingorganisation". In *Vahlen Grosses Controlling Lexikon*, 2nd ed.; Horvath, P., Reichmann, T., Eds.; Verlag, C.H. Beck: München, Germany, 2003.
23. Horvath, P.; Reichmann, T. *Controlling*; Vahlen: München, Germany, 2004.
24. Koźmiński, A.K.; Piotrowski, W. *Zarządzanie. Teoria i praktyka*; Wydawnictwo Naukowe PWN: Warszawa, Poland, 2022; p. 282. ISBN 9788301164416.
25. Krüger, W. Controlling: Gegenstandsbereich, Wirkungsweise und Funktionen im Rahmen der Unternehmenspolitik. *Betr. Forsch. Und Prax.* **1997**, *31*, 158–169.

26. Olejczyk, K. Zarządzanie przez controlling. In *ZarząDzanie Przedsiębiorstwem PrzyszłOśCi: Koncepcje, Modele, Metody*; Perechuda, K., Ed.; Agencja Wydawnicza „Placet": Warszawa, Poland, 2000; pp. 262–268.
27. Penc, J. *Strategie Zarządzania, Perspektywiczne Myślenie, Systemowe Działanie*; Agencja Wydawnicza Placet: Warszawa, Poland, 2002; p. 203. ISBN 8385428070.
28. Volmuth, H.J. *Controlling: Planowanie, Kontrola, Zarządzanie*; Agencja Wydawnicza "Placet": Warszawa, Poland, 2013; p. 15. ISBN 8374881151.
29. Hoffmann, F. Merkmale der Führungsorganisation Amerikanischer Unternehmen. *Z. Für Organ.* **1972**, *41*, 3–8, 85–89, 145–148.
30. Kuc, B. *Zarządzanie Doskonałe: Poszukiwanie Przenikliwości*, 3rd ed.; PTM Wydawnictwo Menedżerskie: Warszawa, Poland, 2008; ISBN 978-83-92421-54-2.
31. Reichmann, T. *Controlling Mit Kennzahlen: Die Systemgestützte Controlling-Konzeption*; Vahlen: München, Germany, 2017; ISBN 978-3-8006-5116-0.
32. Strauss, E.; Zecher, C. Management Control Systems—A Review. *J. Manag. Control* **2013**, *23*, 233–268. [CrossRef]
33. Mitchell, V.L.; Nault, B.R. Cooperative Planning, Uncertainty, and Managerial Control in Concurrent Design. *Manag. Sci.* **2007**, *53*, 375–389. [CrossRef]
34. Thonet, P.J.; Poensgen, O.H. Managerial Control and Economic Performance in Western Germany. *J. Ind. Econ.* **1979**, *28*, 23–37. [CrossRef]
35. Clive, E.; Otley, D.; Merchant, K. *Readings in Accounting for Management Control*; Springer-Science + Business Media, B.V.: Berlin/Heidelberg, Germany, 2013; ISBN 978-0-412-41490-9.
36. Cunningham, G.M. Management Control and Accounting Systems under a Competitive Strategy. *Account. Audit. Account. J.* **1992**, *5*, 23–37. [CrossRef]
37. Lowe, E.A. *Management Control Theory*; Routledge: London, UK, 1998; ISBN 9781138391734.
38. Stanowisko Komisji Rachunkowości Zarządczej i Controllingu Rady Naukowej Stowarzyszenia Księgowych w Polsce. Rachunkowość zarządcza a controlling. *Rachunkowość* **2010**, *3*, 59.
39. Otley, D. Management control and performance management: Whence and whither? *Br. Account. Rev.* **2003**, *35*, 309–326. [CrossRef]
40. Adler, R.W. Performance Management and Organizational Strategy: How to Design Systems that Meet the Needs of Confrontation Strategy Firms. *Br. Account. Rev.* **2011**, *43*, 251–263. [CrossRef]
41. Horváth, P.; Gleich, R.; Seiter, M. *Controlling*; Vahlen: München, Germany, 2015; p. 1. ISBN 978-3-8006-4955-6.
42. Performance Management. *Concepts and Methods*; Nesterak, J., Ziębicki, B., Eds.; Cracow University of Economics Fundation: Cracow, Poland, 2011.
43. Performance Management. *Implementation in Business and Non-Profit Organisations*; Nesterak, J., Ziębicki, B., Eds.; Cracow University of Economics Fundation: Cracow, Poland, 2012.
44. Eschenbach, R. *Controlling*; ASPI Publishing: Praha, Czech Republic, 2004; ISBN 978-80-85963-86-1.
45. Stańczyk, I.; Stuss, M.M. Personnel controlling—Human capital management. Results of selected company listed on GPW. *Int. J. Contemp. Manag.* **2018**, *17*, 241–260. [CrossRef]
46. Nesterak, J. *Controlling Zarządczy. Projektowanie i Wdrażanie*; Oficyna Wolters Kluwer Business: Warszawa, Poland, 2015; ISBN 978-83-264-8536-7.
47. Bin-Nashwan, S.; Abdullah, N.S.; Obaid, M.M. A review of literature in management control system (MCS), business strategy, and firm's performance. *Int. J. Manag. Res. Rev.* **2017**, *7*, 99–112.
48. Goliszewski, J. *Controlling—Koncepcje, Zastosowania, Wdrożenie*; Oficyna Wolters Kluwer Business: Warszawa, Poland, 2015; p. 82. ISBN 978-83-264-3371-9.
49. Janka, M.; Günther, T. Controlling für agiles Management. *Control. Manag. Rev.* **2020**, *64*, 24–33. [CrossRef]
50. Schäffer, U.; Weber, J. Die Digitalisierung wird das Con trolling radikal verändern. *Control. Manag. Rev.* **2016**, *60*, 8–17. [CrossRef]
51. Mocanu, M. Towards a definition of controlling. *Stud. Sci. Res. Econ. Ed.* **2014**, *20*, 62–66. [CrossRef]
52. Abdel-Kadera, M.; Luther, R. The impact of firm characteristics on management accounting practices: A UK-based empirical analysis. *Br. Account. Rev.* **2008**, *40*, 2–27. [CrossRef]
53. Wanderley, C. Privatisation and management accounting change: The drivers of changes in a Brazilian electricity distribution companies. *Rev. Universo Contábil* **2014**, *10*, 94–113. [CrossRef]
54. Adams, R.B.; Santos, J.A.C. Identifying the effect of managerial control on firm performance. *J. Account. Econ.* **2006**, *41*, 55–85. [CrossRef]
55. Ruiz-Palomo, D.; Diéguez-Soto, J.; Duréndez, A.; Santos, J.A.C. Family Management and Firm Performance in Family SMEs: The Mediating Roles of Management Control Systems and Technological Innovation. *Sustainability* **2019**, *11*, 3805. [CrossRef]
56. Lambrecht, B.M.; Myers, S.C. A Lintner model of payout and managerial rents. *J. Financ.* **2012**, *67*, 1761–1810. [CrossRef]
57. Lambrecht, B.M.; Myers, S.C. The dynamics of investment, payout and debt. *Rev. Financ. Stud.* **2017**, *30*, 3759–3800. [CrossRef]
58. Hoang, E.C.; Hoxha, I. A tale of two emerging market economies: Evidence from payout smoothing in China and Taiwan. *Int. J. Manag. Financ.* **2021**, *17*, 361–376. [CrossRef]
59. Denis, D.J.; Osobov, I. Why do firms pay dividends? International evidence on the determinants of dividend policy. *J. Financ. Econ.* **2008**, *89*, 62–82. [CrossRef]

60. Hoang, E.C.; Hoxha, I. The sensitivity of payouts to corporate financing decisions. *J. Financ. Econ. Policy* **2015**, *7*, 290–300. [CrossRef]
61. Hoang, E.; Hoxha, I. An international study of the response of corporate payout policy. *Int. J. Manag. Financ.* **2019**, *15*, 335–349. [CrossRef]
62. Schäffer, U.; Binder, C. "Controlling" as an academic discipline: The development of management accounting and management control research in German-speaking countries between 1970 and 2003. *Account. Hist.* **2008**, *13*, 33–74. [CrossRef]
63. Libby, T.; Lindsay, R.M. Beyond budgeting or budgeting reconsidered? A survey of North-American budgeting practice. *Manag. Account. Res.* **2010**, *21*, 56–75. [CrossRef]
64. Mihalciuc, C.C. Improving the Performance of Small And Medium-Sized Enterprises By Implementing Management Accounting Practices. *Eur. J. Account. Financ. Bus.* **2022**, *10*, 80–87.
65. Johanson, D.; Madsen, D.; Berg, T. The Role of Benchmarking from a Management Accounting and Control Perspective: Evidence from Norwegian Firms. Available online: https://ssrn.com/abstract=4250510 (accessed on 6 October 2022).
66. Ekanayake, E.M.S.S.M.; Swarnapali, R.M.N.C. Impact of management accounting practices on financial performance of listed manufacturing companies in Sri Lanka. In Proceedings of the 1st International Research Symposium on Management 2022, Mihintale, Sri Lanka, 5 October 2022; Available online: http://repository.rjt.ac.lk/bitstream/handle/123456789/5221/13.pdf?sequence=1 (accessed on 6 October 2022).
67. Fullerton, R.R.; Kennedy, F.A.; Widener, S.K. Lean manufacturing and firm performance: The incremental contribution of lean management accounting practices. *J. Oper. Manag.* **2014**, *32*, 414–428. [CrossRef]
68. Gehring, M.; Lux, W. Strategisches Controlling für Familienunternehmen. *Control. Manag. Rev.* **2020**, *64*, 30–38. [CrossRef]
69. Rieg, R.; Gruber, T.; Reißig-Thust, S. Biltroller und Biltrolling: Empirische Ergebnisse zur Zusammenführung von externem Rechnungswesen und Controlling im Mittelstand. *BC Z. Für Bilanzier. Rechn. Und Control.* **2012**, *3*, 100–105.
70. Feldbauer-Durstmüller, B.; Duller, C.; Mayr, S.; Neubauer, H.; Ulrich, P. Controlling in mittelständischen Familienunternehmen—Ein Vergleich von Deutschland und Österreich. *Control. Manag.* **2012**, *56*, 408–413. [CrossRef]
71. Rieg, R.; Reißig-Thust, S.; Gruber, T. Einflussfaktoren auf die Anzahl der Mitarbeiter im Rechnungswesen, Controlling und Biltrolling. *Controlling* **2015**, *27*, 192–199. [CrossRef]
72. ControllerVerein ICV. Available online: https://www.icv-controlling.com/en (accessed on 19 September 2022).
73. GEFIU. Available online: https://www.gefiu.com/ (accessed on 19 October 2022).
74. CA Controller Akademie. Available online: https://www.controllerakademie.de/ (accessed on 8 September 2022).
75. HAUFE. Available online: https://www.haufe.de/controlling/ (accessed on 8 September 2022).
76. Horváth. Available online: https://www.horvath-partners.com/ (accessed on 5 September 2022).
77. Banaszkiewicz, A.; Makowska, E.; Meller, S. Proces wdrażania controllingu w praktyce przedsiębiorstw. *Pr. Nauk. Uniw. Ekon. we Wrocławiu* **2015**, *399*, 22–31. [CrossRef]
78. Bieńkowska, A.; Kral, Z.; Zabłocka-Kluczka, A. Stan, bariery i przesłanki wdrożenia controllingu strategicznego—Wyniki badań ogólnopolskich. *Pr. Nauk. Uniw. Ekon. we Wrocławiu* **2017**, *471*, 46–60.
79. Dynowska, J. Czynniki ograniczające wdrażanie controllingu w świetle badań ankietowych. *Pr. Nauk. Uniw. Ekon. we Wrocławiu* **2015**, *399*, 168–175. [CrossRef]
80. Kuźniarska, A. Bariery implementacji controllingu w sieciach handlu detalicznego. *Acta Univ. Lodz. Folia Oeconomica* **2019**, *5*, 159–172. [CrossRef]
81. Materac, J. Controlling jako koncepcja zorientowana na wynik. *Zesz. Nauk. ZPSB Firma i Rynek* **2020**, *1*, 53–63.
82. Nesterak, J.; Głodziński, E.; Kowalski, M.J. *Controlling Projektu w Praktyce Przedsiębiorstw Działających w Polsce*; Stowarzyszenie Krakowska Szkoła Controllingu: Kraków, Poland, 2016; Available online: https://r.uek.krakow.pl/handle/123456789/2951 (accessed on 16 September 2022).
83. Nesterak, J.; Jabłoński, M.; Kowalski, M.J. *Controlling Procesów w Praktyce Przedsiębiorstw Działających w Polsce*; Wydawnictwo Uniwersytetu Ekonomicznego w Krakowie: Kraków, Poland, 2020; ISBN 978-83-7252-803-2.
84. Nesterak, J.; Kołodziej-Hajdo, M.; Kowalski, M.J. *Rachunek Kosztów w Praktyce Przedsiębiorstw Działających w Polsce*; Stowarzyszenie Krakowska Szkoła Controllingu: Kraków, Poland, 2017; Available online: https://r.uek.krakow.pl/handle/123456789/2950 (accessed on 16 September 2022).
85. Nesterak, J.; Kowalski, M.J.; Czerniachowicz, B. *Controlling Strategiczny w Praktyce Przedsiębiorstw Działających w Polsce*; Stowarzyszenie Krakowska Szkoła Controllingu: Kraków, Poland, 2016; Available online: https://r.uek.krakow.pl/handle/123456789/2949 (accessed on 14 September 2022).
86. Nesterak, J.; Nowak, M.; Kowalski, M.J. *Controlling Personalny w Praktyce Przedsiębiorstw Działających w Polsce*; Cedewu: Warszawa, Poland, 2020; ISBN 978-83-810-2292-7.
87. Nowak, E.; Nowak, M. Badania nad controllingiem w ośrodku wrocławskim. Perspektywa trzydziestolecia 1990–2020. *Zesz. Teor. Rachun.* **2021**, *45*, 85–101. [CrossRef]
88. Nowosielski, K.; Lichtarski, J.M. Metodyka pomiaru stanu zaawansowania controllingu w małych i średnich przedsiębiorstwach. In *Stan Rozwoju i Zakres Stosowania Controllingu Operacyjnego w Małych i Średnich Przedsiębiorstwach*; Wydawnictwo Akademii Ekonomicznej we Wrocławiu: Wrocław, Poland, 2006; Volume 1101, pp. 139–152.
89. Kes, Z.; Kubalańca, L. Controlling w zakładach energetycznych. *Pr. Nauk. Akad. Ekon. we Wrocławiu* **2001**, *902*, 212–218.

90. Tworek, K.; Bieńkowska, A.; Zabłocka-Kluczka, A. Coexistence of business continuity management and controlling: Controlling use as a moderator of relation between BCM maturity and organizational results. *Int. J. Ind. Eng. Manag.* **2019**, *10*, 57–68. [CrossRef]
91. Mihăilăa, M. Managerial accounting and decision making, in energy industry. *Procedia—Soc. Behav. Sci.* **2014**, *109*, 1199–1202. [CrossRef]
92. Rubik, J. Ewolucja controllingu w Energetyce Kaliskiej S.A. *Pr. Nauk. Akad. Ekon. Wrocławiu* **2005**, *1080*, 366–374.
93. Kapustka, K. System wskaźników KPI jako fundament systemu controllingu dokonań w elektroenergetyce. *Pr. Nauk. Uniw. Ekon. Wrocławiu* **2010**, *122*, 204–212.
94. Konsek-Ciechońska, J. Operational and strategic controlling tools in microenterprises—Case study. *Manag. Syst. Prod. Eng.* **2017**, *25*, 278–282. [CrossRef]
95. Tomczak, S.K. Comparison of the Financial Standing of Companies Generating Electricity from Renewable Sources and Fossil Fuels: A New Hybrid Approach. *Energies* **2019**, *12*, 3856. [CrossRef]
96. Rubik, J. *Model controllingu kosztów i jego zastosowanie w zakładach energetycznych, In Koszty w Zarządzaniu Przedsiębiorstwem*; Nowicka-Skowron, M., Ed.; Wydawnictwo AGH: Kraków, Poland, 2006; pp. 263–372. ISBN 83-7464-074-X.
97. Mesjasz-Lech, A. *Rachunek kosztów ekologistyki w ocenie proekologicznej działalności elektrowni cieplnych, In Koszty w Zarządzaniu Przedsiębiorstwem*; Nowicka-Skowron, M., Ed.; Wydawnictwo AGH: Kraków, Poland, 2006; pp. 183–194. ISBN 83-7464-074-X.
98. Sadkowski, W. *Rachunek Kosztów Jakości Jako Narzędzie Efektywnego Zarządzania Kosztami Jakości w Sektorze Energetycznym*; Fundacja na Rzecz Czystej Energii: Poznań, Poland, 2018; pp. 305–401.
99. Potkány, M.; Hašková, S.; Lesníková, P.; Schmidtov, J. Perception of essence of controlling and its use in manufacturing enterprises in time of crisis: Does controlling fulfill its essence? *J. Bus. Econ. Manag.* **2022**, *23*, 957–976. [CrossRef]
100. Szyszłowski, R. Wykorzystanie narzędzi rachunkowości zarządczej w przedsiębiorstwach energetyki cieplnej. *Rynek Energii* **2004**, *4*, 52–54.
101. Hass-Symotiuk, M.; Szyszłowski, R. Kierunki wykorzystania rachunku kosztów działań w zarządzaniu przedsiębiorstwem energetyki cieplnej. *Zesz. Nauk. Uniw. Szczecińskiego. Finans. Rynk. Finans. Ubezpieczenia* **2009**, *18*, 147–158.
102. Rof, L.M.; Farcane, N. Current state and evolution perspectives for management accounting in the energy sector by implementing the ABC method. *Ann. Univ. Oradea Econ. Sci. Ser.* **2011**, *20*, 653–660.
103. Rof, L.M.; Capusneanu, S. Increase the Performance of Companies in the Energy Sector by Implementing the Activity-Based Costing. *Int. J. Acad. Res. Account. Financ. Manag. Sci.* **2015**, *5*, 139–148. [CrossRef] [PubMed]
104. Topor, D.I. ABB-ABC-ABE-ABM Approach for Implementation in the Economic Entities from Energy Industry. *Bus. Manag. Horiz.* **2017**, *5*, 36–48. [CrossRef]
105. Szyszłowski, R. Rachunek kosztów działań w przedsiębiorstwie energetyki cieplnej. Available online: https://www.controlling-24.pl/artykul/koszty-w-zarzadzaniu,rachunek-kosztow-dzialan-w-przedsiebiorstwie-energetyki-cieplnej (accessed on 9 September 2022).
106. Laitinen, E.K. Influence of cost accounting change on performance of manufacturing firms. *Adv. Account.* **2014**, *30*, 230–240. [CrossRef]
107. Canova, A.; Profumo, F.; Tartaglia, M. LCC design criteria in electrical plants oriented to energy saving. *IEEE Trans. Ind. Appl.* **2003**, *39*, 53–58. [CrossRef]
108. Dale, M. A Comparative Analysis of Energy Costs of Photovoltaic, Solar Thermal, and Wind Electricity Generation Technologies. *Appl. Sci.* **2013**, *3*, 325–337. [CrossRef]
109. Soni, V.; Dash, A.P.; Singh, S.P.; Banwet, D.K. Life Cycle Costing Analysis of Energy Options: In Search of Better Decisions towards Sustainability in Indian Power &Energy Sector. *Glob. J. Manag. Bus. Res. A Adm. Manag.* **2014**, *14*, 43–53.
110. Bek-Gaik, B.; Surowiec, A. Controlling finansowy w przedsiębiorstwie energetycznym. *Pr. Nauk. Uniw. Ekon. we Wrocławiu* **2011**, *181*, 13–23.
111. Borowiec, L. Zbilansowana karta dokonań jako instrument controllingu w przedsiębiorstwie energetyki cieplnej. *Rynek Energii* **2011**, *5*, 80–85.
112. Pedell, B.; Schwihel, A. Balanced Scorecard als strategisches Führungsinstrument in der Energiewirtschaft. *Controlling* **2002**, *14*, 45–53. [CrossRef]
113. Haapasalo, H.; Ingalsuo, K.; Lenkkeri, T. Linking strategy into operational management—A survey of BSC implementation in Finnish energy sector. *Benchmarking Int. J.* **2006**, *13*, 701–717. [CrossRef]
114. Urbanek, P.; Walińska, E. *Od controllingu operacyjnego do controllingu finansowego w procesie restrukturyzacji przedsiębiorstwa—analiza przypadku, In Budżetowanie Działalności Jednostek Gospodarczych—Teoria i Praktyka*; Krawczyk, W., Ed.; Wydawnictwo Agh: Kraków, Poland, 2003; pp. 75–89.
115. Urbanek, P. Outsourcing in the Process of Restructuring Enterprises in Light of the Transaction Cost Theory. *Gospod. Nar. Pol. J. Econ.* **2011**, *247*, 69–84. [CrossRef]
116. Kowalewski, M. Umiejscowienie controllingu oraz zasady wyodrębniania ośrodków odpowiedzialności za koszty w Miejskim Przedsiębiorstwie Energetyki Cieplnej Finanse. *Rynk. Finans. Ubezpieczenia* **2017**, *4*, 1. [CrossRef]
117. Mayr, S.; Ausweger, M. CSR-Strategien mittels CSR-Scorecard erfolgreich umsetzen. *Control. Manag. Rev.* **2013**, *4*, 34–42. [CrossRef]

118. Jamil, C.; Mohamed, R.; Muhammad, F.; Ali, A. Environmental management accounting practices in small medium manufacturing firms. *Procedia—Soc. Behav. Sci.* **2015**, *172*, 619–626. [CrossRef]
119. Ferenc, A. Identyfikacja kosztów środowiskowych w rachunku kosztów przedsiębiorstwa branży energetycznej—wyniki badań. *Finans. Rynk. Finans. Ubezpieczenia* **2016**, *2*, 245–253.
120. Adams, C.A.; Larrinaga-González, C. Engaging with organisations in pursuit of improved sustainability accounting and performance. *Account. Audit. Account. J.* **2007**, *20*, 333–355. [CrossRef]
121. Sumit, L.; Kerry, J. The practice turn in environmental reporting: A study into current practices in two Australian commonwealth departments. *Account. Audit. Account. J.* **2007**, *26*, 595–615. [CrossRef]
122. Wahyuni, D.; Ratnatunga, J. Carbon strategies and management practices in an uncertain carbonomic environment: Lessons learned from the coal-face. *J. Clean. Prod.* **2015**, *96*, 397–406. [CrossRef]
123. Schaltegger, S.; Csutora, M. Carbon accounting for sustainability and management. Status quo and challenges. *J. Clean. Prod.* **2012**, *36*, 1–16. [CrossRef]
124. Rietbergen, M.; Blok, K.; Rheede, A. The target-setting process in the CO_2 Performance Ladder: Does it lead to ambitious goals for carbon dioxide emission reduction? *J. Clean. Prod.* **2015**, *103*, 549–561. [CrossRef]
125. Wagenhofer, A. Exploiting regulatory changes for research in management accounting. *Manag. Account. Res.* **2016**, *31*, 112–117. [CrossRef]
126. Kowalewski, M.; Lelusz, H. Przesłanki, bariery i efekty wdrożenia controllingu w opinii kadry menedżerskiej na przykładzie Miejskiego Przedsiębiorstwa Energetyki Cieplnej. *Stud. Oeconomica Posnaniensia* **2018**, *8*, 5–16. [CrossRef]
127. Tillema, S. Towards an integrated contingency framework for MAS sophistication: Case studies on the scope of accounting instruments in Dutch power and gas companies. *Manag. Account. Res.* **2005**, *16*, 101–129. [CrossRef]
128. Ministry of Economy. *Ustawa z Dnia 10 Kwietnia 1997 r. Prawo Energetyczne. Dz. U. z 2022 r. Poz. 1385 i Poz. 1723*; Ministry of Economy: Warsaw, Poland, 1997.
129. Ministry of Economy. *Ustawa z Dnia 29 Września 1994 r. o Rachunkowości. Dz. U. 1994 Nr 121 Poz. 591 z Późn. Zm*; Ministry of Economy: Warsaw, Poland, 1994.
130. ARCHMAN. Available online: https://archman.pl/charakterystyka-platformy/ (accessed on 18 October 2022).
131. Google Forms. Available online: https://www.google.pl/intl/pl/forms/about/ (accessed on 18 October 2022).
132. Nesterak, J. *Controlling—System Oceny Centrów Odpowiedzialności*, 3rd ed.; Anvix: Kraków, Poland, 2004.

energies

Article

The Impact of the COVID-19 Pandemic on the Volume of Fuel Supplies to EU Countries

Izabela Dembińska [1], Agnieszka Barczak [2], Katarzyna Szopik-Depczyńska [3,*], Irena Dul [4], Adam Koliński [5] and Giuseppe Ioppolo [6]

1 Faculty of Economics and Engineering of Transport, Maritime University of Szczecin, 70-507 Szczecin, Poland
2 Faculty of Economics, West Pomeranian University of Technology, 71-270 Szczecin, Poland
3 Institute of Management, University of Szczecin, 71-004 Szczecin, Poland
4 SEC (Szczecińska Energetyka Cieplna), 70-653 Szczecin, Poland
5 Poznan School of Logistics, 61-755 Poznań, Poland
6 Department of Economics, University of Messina, 98122 Messina, Italy
* Correspondence: katarzyna.szopik-depczynska@usz.edu.pl

Abstract: The COVID-19 pandemic is undoubtedly a destructive factor, strongly affecting the economic fields. From the perspective of the countries affected by the pandemic, almost all sectors of the economy saw declines in economic indicators. First, the lockdown and its social consequences contributed to this. The increasing time perspective since the outbreak of the COVID-19 pandemic implies increasingly more studies analyzing its impact on various economic spheres. The aim of the research is to determine the difference in the level of fuel supplies between a pandemic situation and a situation where a pandemic would not occur. We assumed that the pandemic is a determinant of the decline in fuel supplies. The subjects of the analysis were the following fuels: kerosene-type jet fuel, gas oil and diesel oil, motor gasoline, and oil products. The countries of the European Union were analyzed. Monthly data from 2015–2021 provided by Eurostat were used for the analyses. The forecasts for 2020–2021 were determined using the exponential smoothing method. The assumption was shown to be accurate in the case of kerosene-type jet fuel, gas oil, and diesel oil. In this case, there was a clear drop in the level of supplies. The analysis of forecasts shows that if it were not for the COVID-19 pandemic, in the years 2020–2021, in accordance with the forecasts obtained, approximately 31,495 thousand tons of kerosene-type jet fuel and 11,396 thousand tons of gas oil and diesel oil would have been additionally supplied to the EU countries. For oil products, supply volumes also decreased, but unlike previously mentioned fuels, supply levels had not recovered to pre-pandemic levels by the end of 2021. On the other hand, the forecast of deliveries indicates the volume of 95,683 thousand tons of oil products.

Keywords: fuel; fuel supplies; COVID-19; coronavirus; transport; UE; energy economics and management

Citation: Dembińska, I.; Barczak, A.; Szopik-Depczyńska, K.; Dul, I.; Koliński, A.; Ioppolo, G. The Impact of the COVID-19 Pandemic on the Volume of Fuel Supplies to EU Countries. *Energies* **2022**, *15*, 8439. https://doi.org/10.3390/en15228439

Academic Editors: Bernard Ziębicki and Edyta Bielińska-Dusza

Received: 20 August 2022
Accepted: 9 November 2022
Published: 11 November 2022

1. Introduction

The coronavirus (2019-nCoV-COVID-19) pandemic has affected virtually every economic sector to a greater or lesser extent, and its impact and effects are analyzed in numerous publications, taking into account different perspectives and research objects. Despite this variety of research threads, the authors, however, apart from the statistical reports about the fuel demand, did not find any scientific publications in the field of fuel supply during the pandemic times. A search for publications regarding the fuel supply was carried out in the Scopus database. The authors used various combinations of keywords such as: fuel, fuel supply, COVID-19, coronavirus, transport, and EU, as well as aviation kerosene fuel, diesel, motor gasoline, and petroleum products. The search has been narrowed to journals and articles in the field of research "economics and management", and published in 2020, 2021, or 2022. Using the Scopus database, the authors found only one article in the field of social sciences regarding this subject matter. This was the article of Nocera Alves et al. [1]. This article has been cited 2 times so far and is used in our manuscript as a reference. The paper analyses how COVID-19 affected green-fuel supply chain. In comparison with our research problem, the considerations in the cited article concerned Brazil and green fuel. Continuing the analysis of the literature on the fuel market during the pandemic beyond the Scopus base, it was noted that the manuscripts published during those several years were not analyses of the supply factor but only took into account problems related to it in some various areas. The authors grouped them into the following:

- the impact of COVID-19 on fuel consumption and its consequences, including CO_2 emissions;
- the impact of COVID-19 on the economy, financial markets, the energy market, and the environment;
- the impact of COVID-19 on product and service supply chains, transport, and infrastructure.

In the first area, the authors of analyzed publications showed that the economic slowdown caused by the pandemic resulted in a decrease in fuel consumption and energy demand and made attempts to forecast the trend for the coming years. As a result of the research on the COVID-19 impact on the oil and gas industry conducted by Norouzi [2] for the US market, it was shown that the short-term effect was a decrease in oil consumption by almost 25%, while the long-term effect was a decrease in capital expenditure and R&D investments in the oil and gas market by 30–40%, which resulted in a reduction in the demand for oil extraction from over 800 in 2019 to 265 in 2021. The expected decrease in fuel consumption reasonably implied research that also analyzed the level of CO_2 emissions. The expected decrease in fuel consumption reasonably implied research that also analyzed the level of CO_2 emissions. The natural consequence of introducing the lock down was the reduction of fuel consumption in individual passenger transport, which resulted in a lower level of CO_2 emissions [3]. In the study [4], assessing the impact of the COVID-19 pandemic on global consumption of fossil fuels and CO_2 emissions in the two-year horizon 2020Q1–2021Q4, projections of coal, natural gas, and oil consumption were prepared, depending on GDP growth scenarios on the basis of alternative IMF World Economic Outlook forecasts that were drawn up before and after the outbreak. Forecasts show that fossil fuel consumption and CO_2 emissions will return to, or even exceed, pre-pandemic levels within a two-year horizon, despite significant reductions in the first quarter after the outbreak. Interestingly, there will be stronger growth for emerging economies than for developed economies. It is also worth referring to the Fuels Europe report, prepared on the basis of the International Energy Agency's data for 2021, taking into account the impact of COVID-19 on the demand for individual fuels [5]. It shows that the change in demand did not affect all fuels and all regions equally. In fact, while in the European Union and the United States there was a decrease in the consumption of fossil fuels and an increase in the consumption of renewable energy, in Asian countries the demand for all types of fuels increased in 2021 compared with 2019.

Another group of authors and publications focused on the impact of COVID-19 on the economy, financial markets, the energy market, and the environment and presented the effects of measures introduced by the European Union or selected countries aimed at preventing the spread of the virus while also supporting the economy. Dziembała and Kłos verified the hypothesis that the planned financial instruments, implemented at the EU level, should, to some extent, limit the negative consequences of the pandemic; however, it is necessary to conduct close cooperation between Member States and European institutions in the coordination of actions taken and instruments implemented, conditioning their greater effectiveness. The conclusions reached by the authors indicated that despite the measures introduced by the European Commission to prevent the economic crisis, the burden of counteracting the effects of the epidemic rests mainly with the countries whose governments have introduced anti-crisis packages [6]. Other researchers provided a quantified assessment of the economic and environmental impacts of the blocking measures applied in France over the period of 55 years. They showed that the lockdown led to a significant decline in economic output by 5% of GDP, but a positive environmental impact, with a reduction of CO_2 emissions by 6.6% in 2020, while concluding that both declines are temporary, and in the coming years they will revert to pre-pandemic levels [7]. Investors' approach and companies' profits from fossil fuels and clean energy were also topics raised by researchers in the context of fuels and energy. The results are not conclusive. One study found that clean energy companies had superiority and greater resilience to the negative effects of the pandemic over fossil fuel companies [8], while another study found that despite viewing clean energy action as more sustainable and less prone to external shocks, fear and coronavirus-induced investor pessimism had also spread to the renewable energy sector, and no more favorable returns on clean energy shares have been observed [9]. The crisis caused by the COVID-19 virus was not indifferent to the natural environment. This relationship was investigated using the Kuznets curve [10], which allowed scientists to formulate a recommendation for economic policy. According to this, an economy in a crisis may take place through investment support and through environmentally friendly legal and organizational solutions [11].

Many authors of the analyzed publications raised the issues related to the supply chains of products and services, as well as related transport or infrastructure in the times of COVID-19. However, no publications dealing with the topic of fuel supplies to the European Union countries have been found, which indicates a literature and research gap in this area. Fuel supply issues were raised, but only in the context of the aviation sector, in an article presenting the relationship between the number of air operations and the volume of aviation fuel delivered to an airport. The analysis showed an increase in the strength of the relationship between the number of air operations performed and the volume of fuel supplies during the pandemic compared with the pre-pandemic period, which brought practical conclusions leading to the optimization of fuel supply chain management in the aviation sector [12]. In general, disruptions in supply chains were investigated by Butt, who showed that manufacturers were fine-tuning production schedules to meet production challenges. Distributors worked with secondary suppliers to meet stock shortages. Finally, procurement firms evaluated the impact of demand by focusing on a short-term demand and supply strategy, preparing for channel changes, opening up additional channels of communication with key customers, and becoming more flexible [13]. Another study found that global supply chains were at that time facing disruptions due to several sources of inherent uncertainty, including natural disasters, war and terrorism, external legal issues, economic and political instability, social and cultural harm, and disease. Flaws in the then-current global supply chain have been exposed, resulting in delays, non-delivery, labor shortages, and fluctuations in demand. These supply chain threats have a strong impact on supply chain performance indicators and the magnitude of their impact is amplified in the context of globalization and the COVID-19 pandemic [14].

Many of the supply studies have focused on one of the most problematic sectors, the food sector. The pandemic proved to be an unprecedented challenge for this sector. COVID-19 reduced the security of the food supply chain, increased logistics costs, and radically changed consumer preferences. The industry associated with perishable products, e.g., dairy products, was particularly severely affected by the negative effects of the pandemic. A positive effect of the pandemic is the increased awareness of food waste and the importance of the independence of food production [15–17]. The resilience of supply chains to COVID-19 in the agricultural sector was also examined, showing that agricultural transport systems proved to be extremely robust and able to innovate in real time [18]. Disruptions in supply for medical care [19] were also analyzed, and the impact of the COVID-19 pandemic on the scope and quality of services of courier companies operating on the Polish market was also assessed [20]. Supply chain issues, which may also apply to fuels, were also raised, such as:

- disruptions in freight transport—the changes resulting from the adaptation of the law to the changing situation in the Polish railway sector were analyzed, which led to the conclusion that the introduced legal solutions, although assessed positively, were insufficient [21],

- the problem of preventing COVID-19 infection by employees of hard coal mines through the implementation of safe work systems in mining during a pandemic [22].

Taking into consideration the above, to the best of authors' knowledge, no study has assessed the impacts of COVID-19 on fuel supplies to European Union countries. Therefore, the study presented in this paper is intended to fill the literature and research gap. The aim of the research is, therefore, to determine the difference in the level of fuel supplies between a pandemic situation and a situation where a pandemic would not occur. We assume that the implication of a pandemic would be a decrease in fuel supplies. The impact of the pandemic was quite easy to predict. It had been known from the beginning that the pandemic would have a negative impact on the economy and society. Regarding this context, in our study, we do not ask whether the pandemic will have negative consequences or whether it will cause a decrease in fuel supplies. We are interested mainly in the distribution of changes in fuel supply broken down by fuel groups and in the course of the phenomenon over time. We consider such research justified from the perspective of knowledge about the course of the pandemic, treating the pandemic as a crisis situation. The topic is, therefore, topical and important, although it should be emphasized that our research is cognitive rather than epistemological.

This paper is categorized into different sections as follows: Section 2 provides an explanation of the data and the methodology of this study. The estimated results and discussion are presented in Section 3. The conclusion and limitations of our research are presented in Section 4.

2. Materials and Methodology

The study covered the volume of fuel supplies to European Union countries, considering kerosene-type jet fuel, gas oil and diesel oil, motor gasoline, and oil products.

Kerosene-type jet fuel is "distillate used for aviation turbine power units. It has the same distillation characteristics at between 150 °C and 300 °C (generally not above 250 °C) and flash point as kerosene. In addition, it has specifications (such as freezing point) which are established by the International Air Transport Association. Includes kerosene blending components. Kerosene type jet fuel is a product aggregate equal to the sum of blended bio jet kerosene (bio jet kerosene in kerosene type jet fuel) and non-bio jet kerosene" [23].

Gas/diesel oil is "primarily a medium distillate distilling at between 180 °C and 380 °C. Includes blending components. Several grades are available depending on uses. Gas/diesel oil includes on-road diesel oil for diesel compression ignition engines of cars and trucks. Gas/diesel oil includes light heating oil for industrial and commercial uses, marine diesel and diesel used in rail traffic, other gas oil including heavy gas oils which distil at between 380 °C and 540 °C and which are used as petrochemical feedstocks. Gas/diesel oil is a product aggregate equal to the sum of blended biodiesels (biodiesels in gas/diesel oil) and non-biodiesels" [24].

Motor gasoline "consists of a mixture of light hydrocarbons distilling at between 35 °C and 215 °C. It is used as a fuel for land-based spark ignition engines. Motor gasoline may include additives, oxygenates and octane enhancers, including lead compounds. Includes motor gasoline blending components (excluding additives/oxygenates), e.g., alkylates, isomerate, reformate, cracked gasoline destined for use as finished motor gasoline. Motor gasoline is a product aggregate equal to the sum of blended biogasoline (biogasoline in motor gasoline) and non-biogasoline" [25].

Oil products is "petroleum products are a product aggregate equal to the sum of refinery gas, ethane, liquefied petroleum gases, naphtha, motor gasoline, aviation gasoline, gasoline type jet fuel, kerosene type jet fuel, other kerosene, gas/diesel oil, fuel oil, white spirit ad SPB, lubricants, bitumen, paraffin waxes, petroleum coke and other products" [26].

Monthly data for 2015–2021 provided by Eurostat were used for the analyses. It should be noted that because Great Britain left the EU structure on 1 February 2020, it was not included in the research. This is due to the fact that the participation of GB in the analyses and its subsequent withdrawal from them may distort forecasts.

The forecasts for 2020–2021 were determined using the exponential smoothing method. Exponential smoothing is a method where the time series of the predicted variable is smoothed using a weighted moving average. This involves replacing each element of the series with a weighted mean of *n* adjacent values, where n is the so-called width of the smoothing window. It should be noted that the weights are determined according to the exponential law. The alpha and delta parameters used in the modeling (the smoothing parameter of the seasonal syntax) were selected using an automatic search for the best value of the parameter using the quasi-Newtonian function minimization procedure (Statistica 13.3). These values are selected on the basis of minimizing the mean square error of the ex-post forecast, i.e., minimizing the sum of squared differences between the empirical values and those forecasted for one period ahead. When carrying out the exponential smoothing process, one can rely on various models, adjusted to the type of components of the predicted time series. Due to the fact that the exponential smoothing method has been extensively described in publicly available publications [27–33], this element was omitted in the study, focusing on the analysis of the obtained results.

The research methodology used might not seem innovative, but the authors believe that due to the fact that the topic itself is an element of novelty in the literature on the subject, there is no need for an innovative statistical method to be used in this respect. We believe that since the literature on the subject lacks publications on fuel supplies to EU countries, the application of the proposed methodology of statistical analyses is sufficient at this point. The authors are already filling the research gap with the topic of the lack of publications in this area toward the number that we would expect.

Due to the fact that the literature contains a multitude of formulas for determining forecast errors, the following formulas were selected for the purposes of the analysis:

Mean error (ME) is derived from the formula:

$$\mathrm{ME} = \frac{1}{\mathrm{m}} \sum_{\mathrm{t}=1}^{\mathrm{m}} \left(\mathrm{y_t} - \mathrm{y_t^P} \right) \tag{1}$$

where:

m—number of observations,

$\mathrm{y_t}$—value observed over time,

$\mathrm{y_t^P}$—forecast value at time t.

Mean error is known as the measurement uncertainty or the difference between the measured value and true value.

Mean absolute error (MAE) is derived from the formula:

$$\mathrm{MAE} = \frac{1}{\mathrm{m}} \sum_{\mathrm{t}=1}^{\mathrm{m}} \left| \mathrm{y_t} - \mathrm{y_t^P} \right| \tag{2}$$

Mean absolute error determines by how much, on average, the actual realizations of the forecast variable will deviate—in absolute value—from the forecasts.

Mean percentage error (MPE) is derived from the formula:

$$\mathrm{MPE} = \frac{\sum_{\mathrm{t}=1}^{\mathrm{m}} \mathrm{PE_t}}{\mathrm{m}} \tag{3}$$

where

$$\mathrm{PE_t} = \frac{\left(\mathrm{y_t} - \mathrm{y_t^P} \right)}{\mathrm{y_t}} \cdot 100 \tag{4}$$

This error determines what percentage of actual implementations of the forecasted variable are forecast errors in the prediction period.

Mean percentage absolute error (MAPE) is derived from the formula:

$$\mathrm{MAPE} = \frac{1}{m}\sum_{t=1}^{m}\left|\frac{y_t - y_t^P}{y_t}\right|\cdot 100 \quad (5)$$

This error determines the average size of forecast errors, expressed as a percentage of the actual values of the forecast variable.

3. Results

3.1. Kerosene-Type Jet Fuel Supplies

In 2015–2019, the volume of aviation fuel deliveries to EU countries was characterized by seasonality, recording increases and decreases in the same months. Stopping or significantly reducing air traffic during the COVID-19 pandemic resulted in a large drop in deliveries in 2020–2021 (Figure 1). Despite the resumption of air traffic after the pandemic stopped, the level of aviation fuel supplies at the end of 2021 was lower by 336.178 thousand tonnes than in 2015, and significantly fewer passengers were handled (Figure 2). The analysis of air traffic in selected EU countries can be found, among others, in work [34].

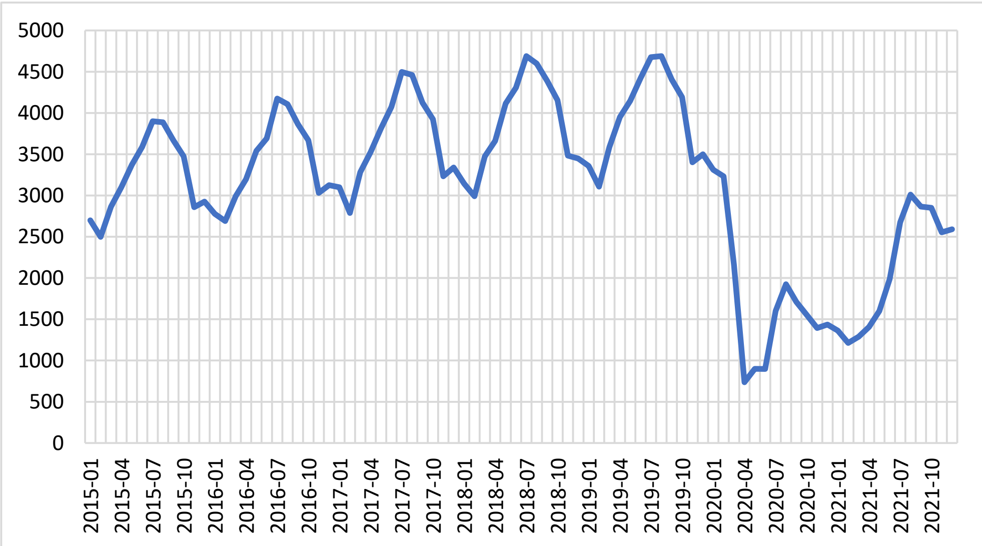


Figure 1. The evolution of the volume of kerosene-type jet fuel supplies to EU countries (in thousand tonnes). Source: own elaboration.

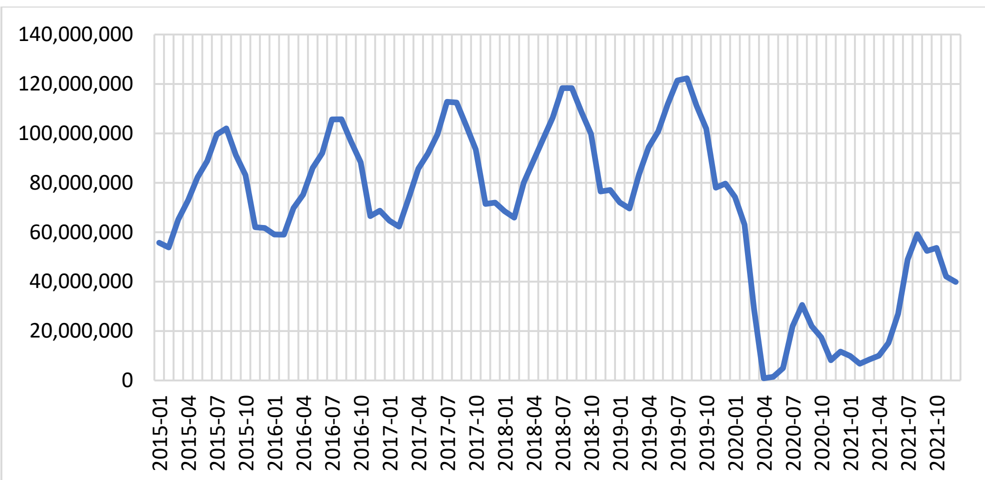


Figure 2. Number of passengers served (in persons). Source: own elaboration.

Due to the features of the series, we decided to use the exponential smoothing method with additive seasonality. The results obtained with the use of Statistica 13.3 software are shown in Figure 3.

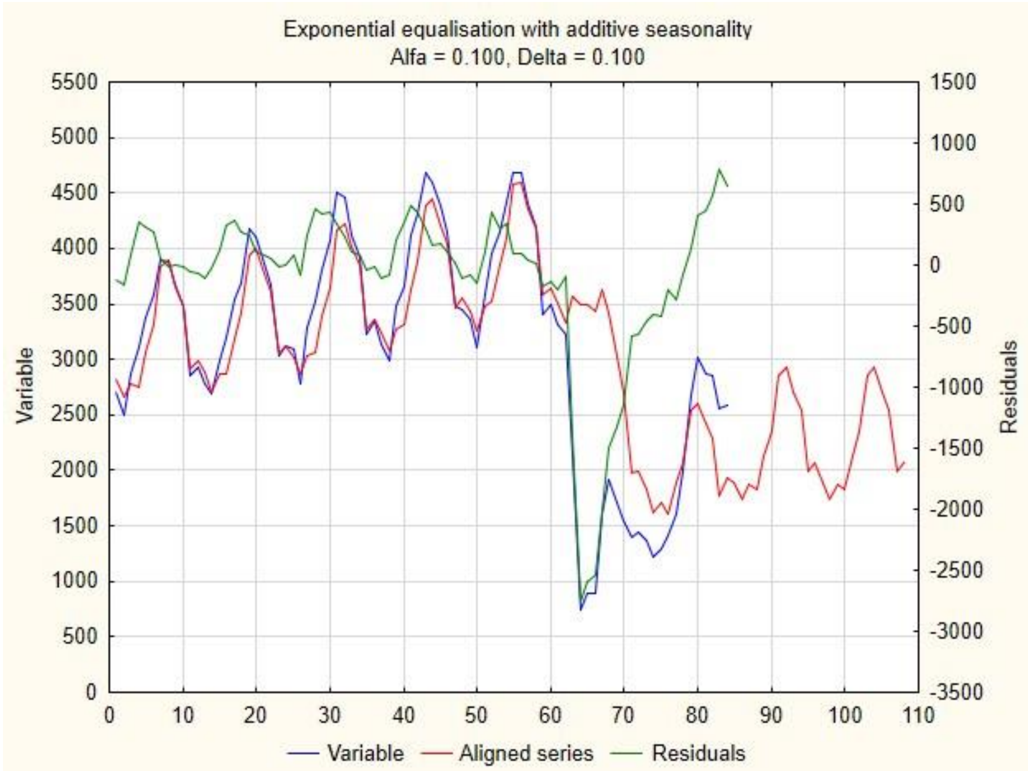


Figure 3. Exponential smoothing of kerosene-type jet fuel supplies. Source: own elaboration.

The values of the forecasts obtained on the basis of this are presented in Table 1, and the forecast errors are in Table 2.

Table 1. Monthly kerosene-type jet fuel supply forecasts for 2020–2021 (in thousands of tones). Source: own elaboration.

Period	Forecast	Period	Forecast
2020-01	1894.612	2021-01	1894.612
2020-02	1739.484	2021-02	1739.484
2020-03	1872.243	2021-03	1872.243
2020-04	1834.793	2021-04	1834.793
2020-05	2119.391	2021-05	2119.391
2020-06	2346.762	2021-06	2346.762
2020-07	2850.966	2021-07	2850.966
2020-08	2929.051	2021-08	2929.051
2020-09	2702.377	2021-09	2702.377
2020-10	2535.197	2021-10	2535.197
2020-11	1988.844	2021-11	1988.844
2020-12	2060.526	2021-12	2060.526

Table 2. Forecast errors. Source: own elaboration.

Mean Error (ME)	Mean Absolute Error (MAE)	Mean Percentage Error (MPE)	Mean Percentage Absolute Error (MAPE)
−100.0174	378.6853	15.5358	23.5667

Mean error indicates a slight positive deviation from zero. This means that the obtained forecasts are slightly underestimated. Mean absolute error indicates that the actual deliveries of kerosene-type jet fuel, in absolute terms, will diverge from forecasts by approximately 378.6853 thousand tonnes. It also shows that 15.5358% of actual deliveries of kerosene-type jet fuel are forecast errors in the prediction period (MPE), and the average value of forecast errors is 23.5667% of the volume of kerosene-type jet fuel (MAPE) deliveries.

The analysis of the obtained forecasts shows that, had it not been for the COVID-19 pandemic, in the years 2020–2021, in accordance with the forecasts obtained, approximately 31,494.910 thousand tonnes of kerosene-type jet fuel would have been delivered to the EU countries in the years 2020–2021 (Figure 4).

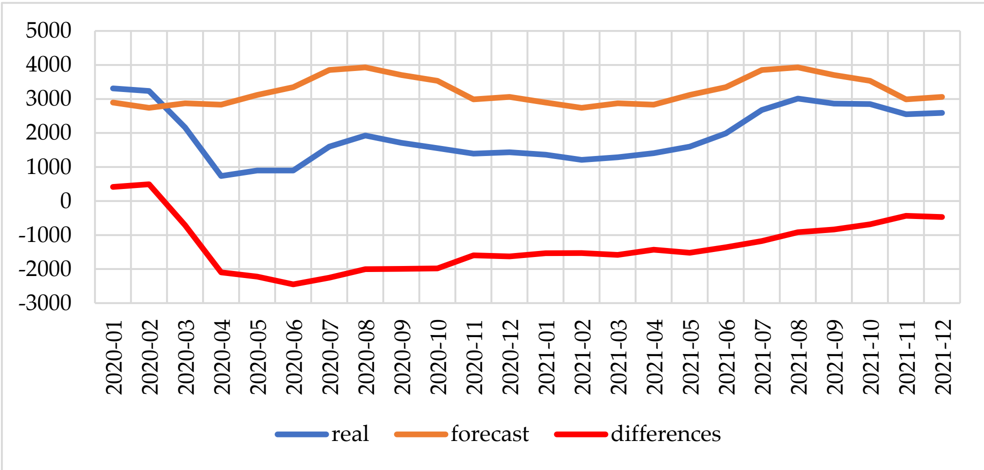


Figure 4. Comparison of the actual and forecast volumes of delivered kerosene-type jet fuel (in thousand tonnes). Source: own elaboration.

3.2. Gas Oil and Diesel Oil Supplies to EU Countries

As in the case of kerosene-type jet fuel deliveries, the volumes of gas oil and diesel oil deliveries decreased significantly as a result of the COVID-19 pandemic. By the end of 2021, the plurality of deliveries of this type of fuel was beginning to return to the pre-pandemic state (Figure 5).

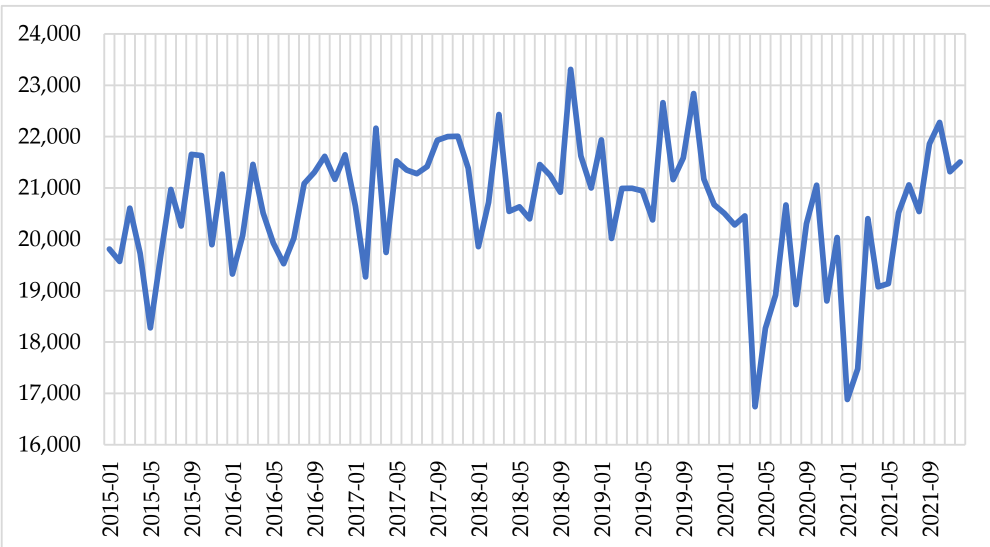


Figure 5. Changes in the volume of gas oil and diesel oil supplies to EU countries (in thousand tonnes). Source: own elaboration.

In the case of gas oil and diesel oil supplies, due to the characteristics of the series, we decided to use the exponential smoothing method with additive seasonality. The results obtained with the use of Statistica 13.3 software are shown in Figure 6.

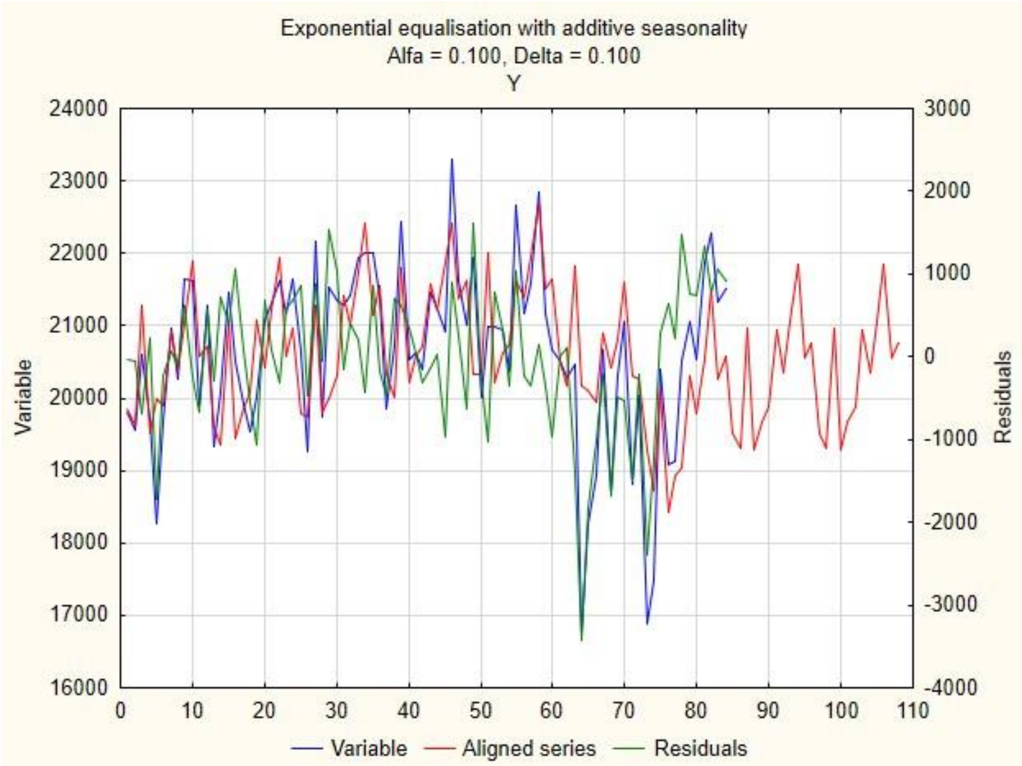


Figure 6. Exponential smoothing of gas oil and diesel oil supplies. Source: own elaboration.

The values of the forecasts obtained on the basis of this are presented in Table 3, and the forecast errors are in Table 4.

Table 3. Monthly gas oil and diesel oil supply forecasts for 2020–2021 (in thousand tonnes). Source: own elaboration.

Period	Forecast	Period	Forecast
2020-01	19,521.38	2021-01	19,521.38
2020-02	19,311.86	2021-02	19,311.86
2020-03	20,960.80	2021-03	20,960.80
2020-04	19,281.69	2021-04	19,281.69
2020-05	19,664.21	2021-05	19,664.21
2020-06	19,875.59	2021-06	19,875.59
2020-07	20,930.39	2021-07	20,930.39
2020-08	20,345.36	2021-08	20,345.36
2020-09	21,062.02	2021-09	21,062.02
2020-10	21,843.90	2021-10	21,843.90
2020-11	20,552.34	2021-11	20,552.34
2020-12	20,756.58	2021-12	20,756.58

Table 4. Forecast errors. Source: own elaboration.

Mean Error (ME)	Mean Absolute Error (MAE)	Mean Percentage Error (MPE)	Mean Percentage Absolute Error (MAPE)
−30.7180	666.4146	0.3420	3.3248

Mean error indicates a slight negative deviation from zero. This means that the obtained forecasts are slightly overestimated. Mean absolute error indicates that the actual deliveries of gas oil and diesel oil, in absolute terms, will diverge from forecasts by approximately 666.4146 thousand tonnes. It also shows that 0.3420% of the actual volume of gas oil and diesel oil supplies are due to forecast errors in the prediction period (MPE), while the average size of forecast errors is 3.3248% of the volume of gas oil and diesel oil (MAPE) supplies.

The analysis of the obtained forecasts shows that if it were not for the COVID-19 pandemic, the EU countries in 2020–2021, according to the forecasts obtained, would have received an additional amount of approximately 11,395.539 thousand tonnes of gas oil and diesel oil (Figure 7).

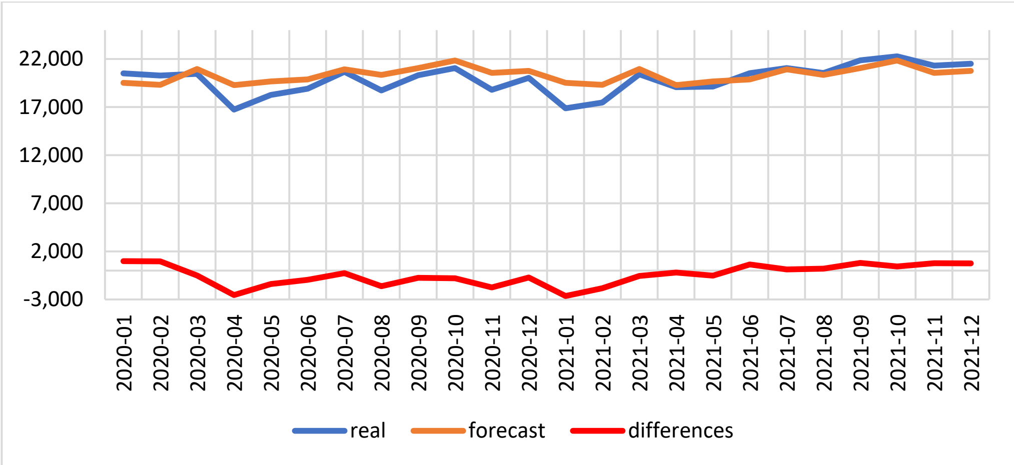


Figure 7. Comparison of the actual and forecast volumes of supplied gas oil and diesel oil (in thousand tonnes). Source: own elaboration.

3.3. Motor Gasoline Supplies to EU Countries

In the case of motor gasoline, the supply volumes did not decrease as a result of the COVID-19 pandemic. Throughout the duration of the COVID-19 pandemic, as well as after its completion, the volumes of deliveries remained at a similar level, taking into account seasonal fluctuations (Figure 8).

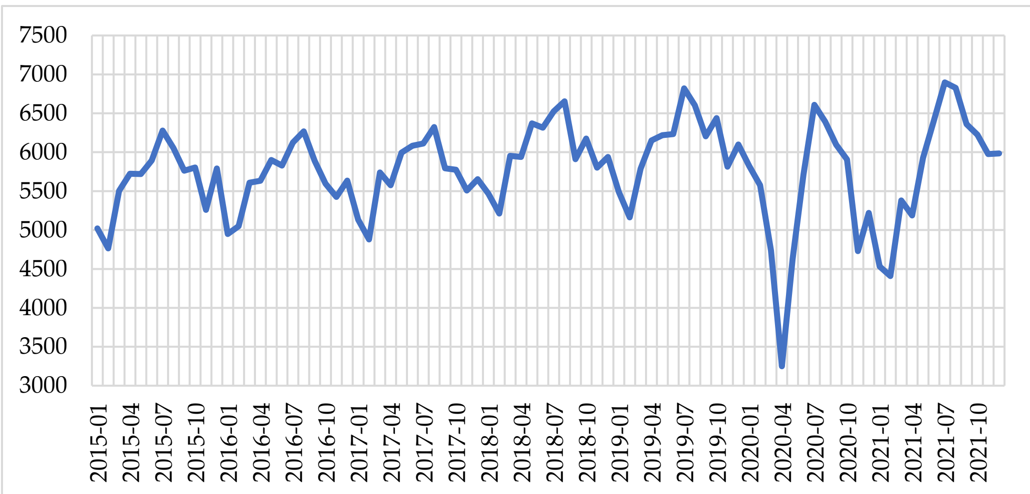


Figure 8. Changes in the volume of motor gasoline supplies to EU countries (in thousand tonnes). Source: own elaboration.

In this case, the method of exponential smoothing with additive seasonality was also used. The results obtained with the use of Statistica 13.3 software are shown in Figure 9.

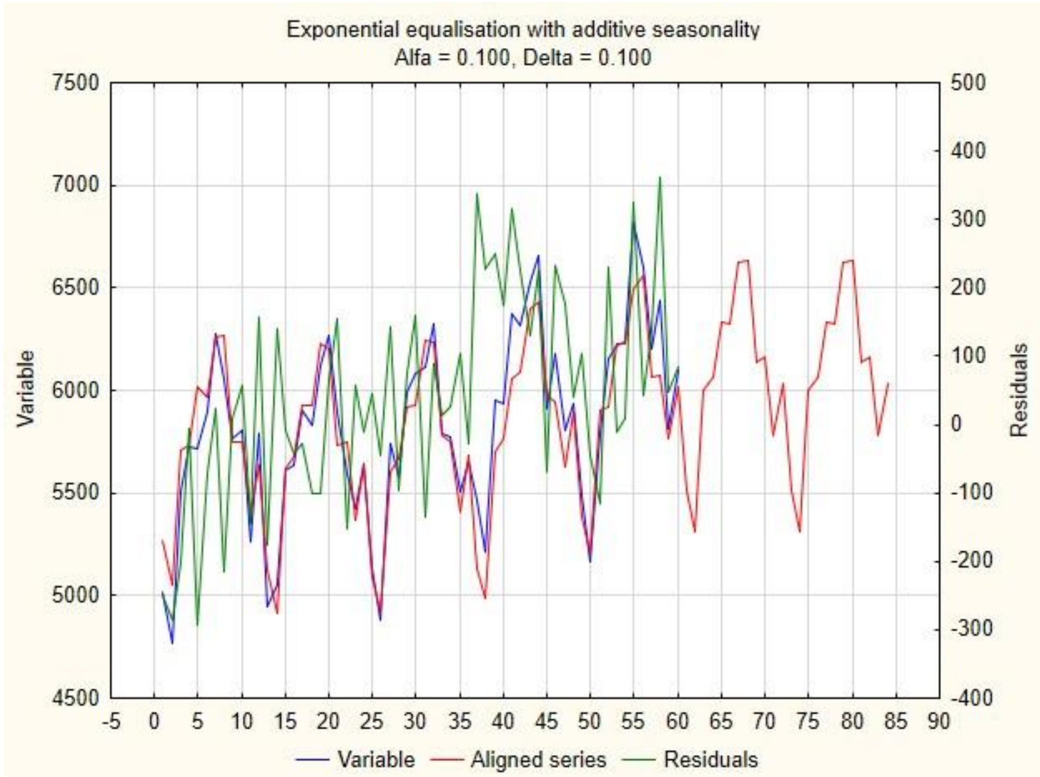


Figure 9. Exponential smoothing of motor gasoline supplies. Source: own elaboration.

The values of the forecasts obtained on the basis of this are presented in Table 5, and the forecast errors are in Table 6.

Table 5. Motor gasoline supply forecasts on a monthly basis for 2020–2021 (in thousand tonnes). Source: own elaboration.

Period	Forecast	Period	Forecast
2020-01	5512.601	2021-01	5512.601
2020-02	5311.355	2021-02	5311.355
2020-03	6002.709	2021-03	6002.709
2020-04	6063.418	2021-04	6063.418
2020-05	6328.656	2021-05	6328.656
2020-06	6325.850	2021-06	6325.850
2020-07	6625.590	2021-07	6625.590
2020-08	6631.529	2021-08	6631.529
2020-09	6141.273	2021-09	6141.273
2020-10	6159.025	2021-10	6159.025
2020-11	5785.373	2021-11	5785.373
2020-12	6031.271	2021-12	6031.271

Table 6. Forecast errors. Source: own elaboration.

Mean Error (ME)	Mean Absolute Error (MAE)	Mean Percentage Error (MPE)	Mean Percentage Absolute Error (MAPE)
39.3798	127.1338	0.5838	2.1901

Mean error indicates a slight positive deviation from zero. This means that the obtained forecasts are slightly underestimated. Mean absolute error indicates that the actual deliveries of motor gasoline, in absolute terms, will deviate from the forecasts by an average of 127.1338 thousand tonnes. This also shows that 0.5838% of the actual deliveries of motor gasoline are forecast errors in the prediction period (MPE), and the average value of forecast errors is 2.1901% of the volume of motor gasoline (MAPE) deliveries.

The analysis of the obtained forecasts shows that despite the apparent maintenance of the trend throughout the entire duration of the COVID-19 pandemic in 2020–2021, according to the forecasts obtained, approximately 11,042.207 thousand tonnes of motor gasoline would have been delivered to the EU countries (Figure 10).

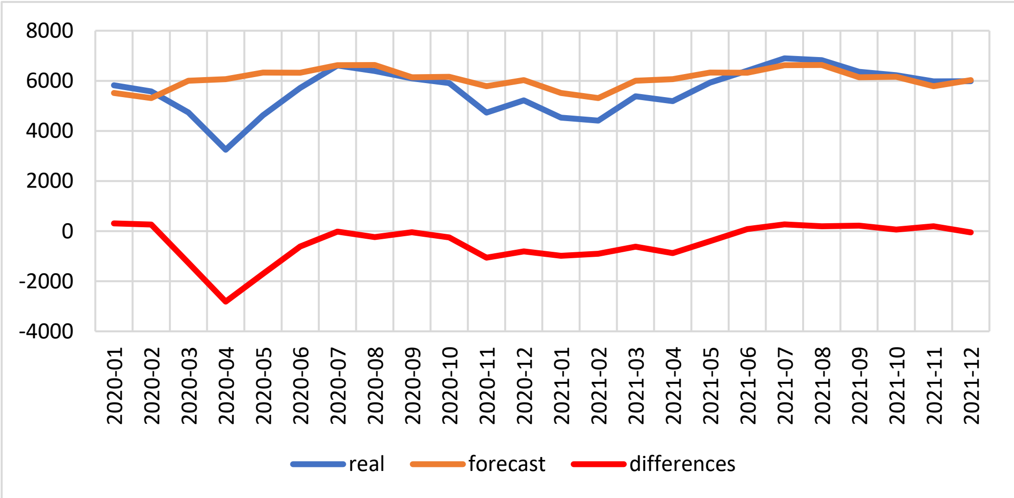


Figure 10. Changes in the volume of motor gasoline supplies to EU countries (in thousand tonnes). Source: own elaboration.

3.4. Deliveries of Oli Products to EU Countries

For oil products, supply volumes have decreased as a result of the COVID-19 pandemic. By the end of 2021, these figures did not return to the pre-pandemic state (Figure 11).

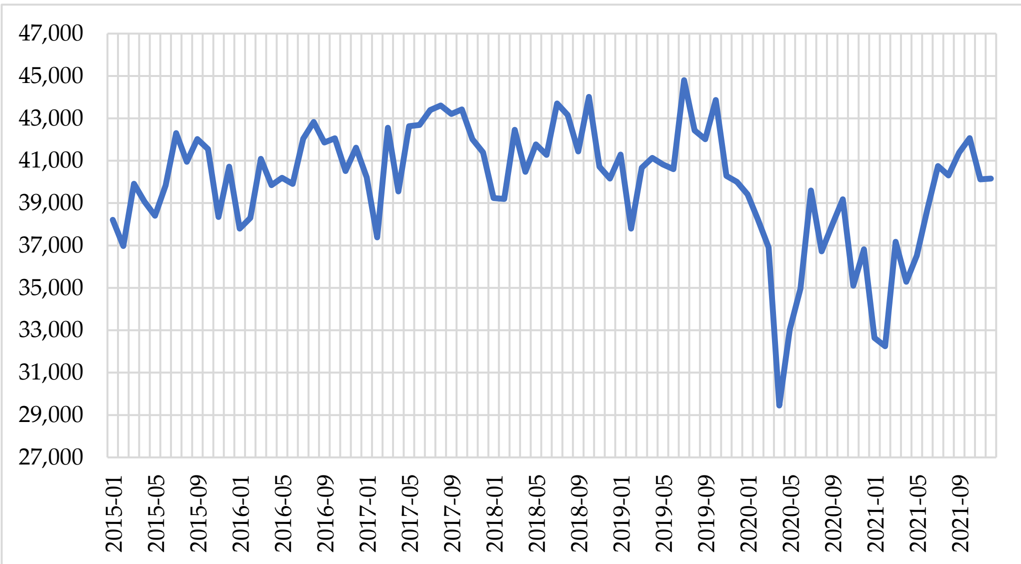


Figure 11. Shaping the volume of deliveries of oil products to EU countries (in thousand tonnes). Source: own elaboration.

In this case, the method of exponential smoothing with additive seasonality was also used. The results obtained with the use of Statistica 13.3 software are shown in Figure 12.

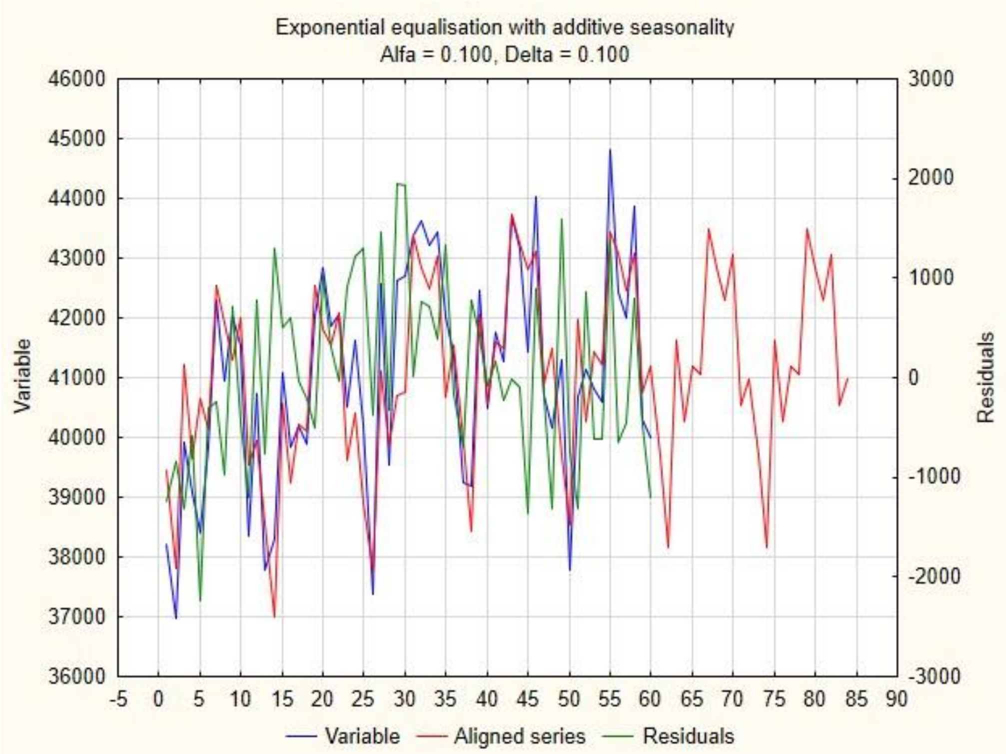


Figure 12. Exponential smoothing of supply volumes of oil products. Source: own elaboration.

The values of the forecasts obtained on the basis of this are presented in Table 7, and the forecast errors are in Table 8.

Table 7. Forecasts of the volume of oil products supplies on a monthly basis for 2020–2021 (in thousand tonnes). Source: own elaboration.

Period	Forecast	Period	Forecast
2020-01	39,698.28	2021-01	39,698.28
2020-02	38,173.78	2021-02	38,173.78
2020-03	41,634.89	2021-03	41,634.89
2020-04	40,258.81	2021-04	40,258.81
2020-05	41,199.79	2021-05	41,199.79
2020-06	41,043.89	2021-06	41,043.89
2020-07	43,486.50	2021-07	43,486.50
2020-08	42,830.51	2021-08	42,830.51
2020-09	42,296.38	2021-09	42,296.38
2020-10	43,062.50	2021-10	43,062.50
2020-11	40,545.24	2021-11	40,545.24
2020-12	40,973.40	2021-12	40,973.40

Table 8. Forecast errors. Source: own elaboration.

Mean Error (ME)	Mean Absolute Error (MAE)	Mean Percentage Error (MPE)	Mean Percentage Absolute Error (MAPE)
36.8596	764.8841	0.0406	1.8740

Mean error indicates a slight positive deviation from zero. This means that the obtained forecasts are slightly underestimated. Mean absolute error indicates that actual oil product deliveries, in absolute terms, will deviate from forecasts by an average of 764.8841 thousand tonnes. It also shows that 0.0406% of the actual oil product deliveries are due to forecast errors in the prediction period (MPE), while the average forecast error is 1.8740% of the oil product deliveries (MAPE).

The analysis of the obtained forecasts shows that if it were not for the COVID-19 pandemic, in the years 2020–2021, in accordance with the forecasts obtained, approximately 95 683.166 thousand tonnes of oil products would have been delivered to the EU countries in the years 2020–2021 (Figure 13).

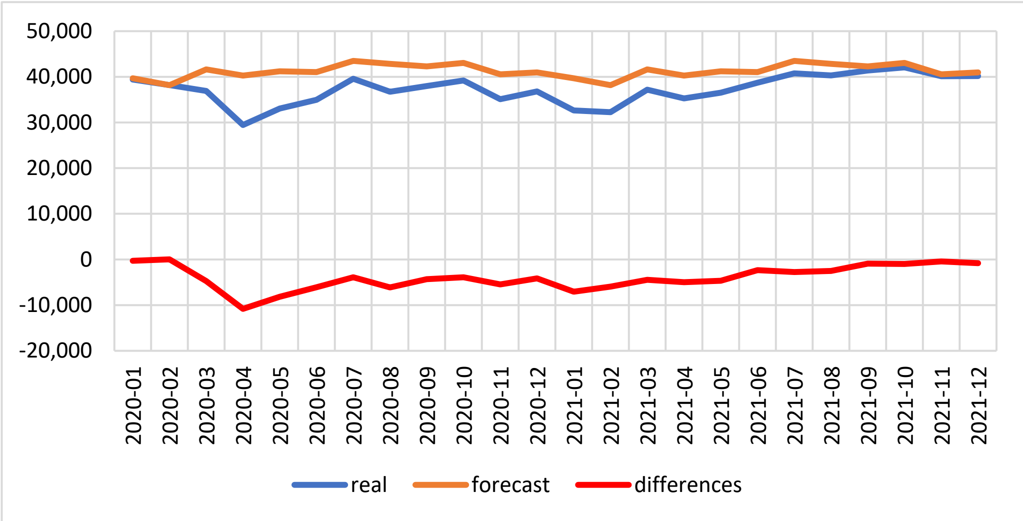


Figure 13. Comparison of the actual and forecast volumes of supplied oil products (in thousand tonnes). Source: own elaboration.

3.5. Discussion

On 30 January 2020, the World Health Organization (WHO) announced a public health emergency of international concern in connection with the COVID-19 epidemic. At the end of February 2020, WHO issued a recommendation [35] underlining the importance of not imposing any travel or trade restrictions due to the outbreak. Toward the end of the first quarter of 2020, governments around the world began imposing restrictions and then prohibitions on international travel. While these restrictions initially applied primarily to China, where the pandemic began, they quickly spread to other areas as well. On 11 March 2021, the WHO classified the epidemic COVID-19 as a pandemic [36]. The United States announced a suspension of travel from Europe, and a week later, the EU closed its external borders to air passengers [37,38]. As the epidemiological situation worsened, individual countries EU Member States began closing their borders to commercial air traffic from other countries within the EU. By April 2020, 14 Schengen Member States introduced internal border controls. The tourist traffic was closed, as was business travel, which was replaced by on-line business sessions.

While previous crises have slowed down the growth of the aviation industry, none of them led to a complete halt to operations. For example, in 2002, after the terrorist attacks in the United States, air traffic in Europe fell by 2%. The 2009 financial crisis saw a decline of 6.6%, and the eruption of Iceland's Eyjafjallajökull volcano in April 2010 resulted in the cancellation of 111,000 flights [39]. However, it is the COVID-19 pandemic that is unprecedented in history in terms of the magnitude of the effects and the timing of the impact. The International Air Transport Association (IATA) expects a recovery to the pre-pandemic situation no sooner than post-2024. Overall, the number of travelers is projected to reach 4.0 billion in 2024 (counting multi-sector connecting journeys as one passenger), exceeding pre-COVID-19 levels (103% of the 2019 total) [40].

The lockdown introduced as a result of COVID 19 also influenced the level of mobility in road transport. In this case as well, there was practically no tourist traffic. Restrictions on social distancing and the need to close hotels prevented people from going anywhere. The transition to distance learning and remote work led people to reduce the use of their cars. Interestingly, many companies discovered the advantages of remote work to such an extent that they want to either completely or partially stay with this form of work.

Fuel supplies are a response to the demand for them. It is of a secondary nature, as it results from the demand for transport [41]. This relationship has been highlighted by the pandemic.

An interesting situation occurred with regard to cargo transportation. Despite the freezing of economies in the EU countries, transport companies did not suffer due to the bad economic situation. The main factor behind this situation was the dynamic growth of e-commerce as a result of restrictions in traditional trade. In the EU-27.2, retail sales via mail order houses or the internet increased by 30% in April 2020 compared with April 2019, while total retail sales decreased by 17.9% [42]. The pandemic, together with its limitations, became a strong stimulus for the growth of online purchases, which, in turn, influenced the situation of transport and logistics companies, and consequently also the demand for fuel.

A pandemic is a crisis. It creates uncertainty and unpredictability. Contemporary supply chains, including those in which fuel flows, must be resilient. Resilience is a synergy of flexibility and adaptability [43,44]. The desired state of resilience is security, stability, and functionality. The resilient supply chain is characterized by the ability to reactive response, adaptation, and resilience in changing, unpredictable, and uncertain operating conditions. Unfortunately, analyzing the COVID-19 pandemic in terms of the resilience of fuel supply chains is still an unspoken but necessary discussion.

4. Conclusions

The COVID-19 pandemic had a significant impact on many sectors of the economy. The fuel sector in the EU was one of the sectors of the economy that felt its direct effects, as it led to massive disruptions to mobility, air traffic, and traditional trade. The aim of our research was to estimate the difference in fuel supplies between the situation where the COVID-19 pandemic occurred and the situation where there was no pandemic. The analysis covered the countries of the European Union. The research was based on the assumption that during the pandemic, fuel supplies had decreased. Our assumption proved to be correct. Only in the case of motor gasoline, the supply volumes did not decrease as a result of the COVID-19 pandemic. Throughout the pandemic, and after its completion, the volumes of deliveries remained at a similar level, taking into account seasonal fluctuations. The decline in fuel supplies was caused mainly by the introduction of lockdown and related social restrictions, which translated into the functioning of almost all sectors of the economy.

This study showed that all lower fuel supplies were, in fact, determined by top-down blockades (hence regional discrepancies) and, thus, "artificially" caused by lower demand. However, the differences between the period—without a pandemic and during a pandemic—are not as great as it seems since the whole world practically stopped. This, in turn, leads to the conclusion that as long as we do not replace fossil fuels with low or zero emission sources, we will not be able to significantly move away from burning fossil fuels (e.g., through energy saving, the pandemic showed that even "forced" did not provide much change) and greenhouse gas emissions.

When reviewing the literature in the research area, it was revealed that there is a huge research gap in this area. There are practically no studies on the impact of COVID-19 on fuel supplies in EU countries. The statistical data are available, however, and this enables various analyses to be performed. The lack of literature is a limitation for our research as no direct comparative analysis is possible. Perhaps a longer time perspective is needed. In addition, as part of the limitations of the study, the research methodology used might not seem innovative, but the authors believe that due to the fact that the topic itself is a novelty, there is no need to use a very innovative method of analysis in this respect. We believe that since the literature on the subject lacks publications on fuel supplies to EU countries, the application of the proposed methodology of statistical analysis is sufficient at this point.

Since the authors find the topic very significant, in terms of further research directions, the plan is to continue the analysis with the use of other statistical methods. The study of the impact of COVID-19 on the volume of fuel supplies has great research potential. In the current study, we wanted to analyze the supply–demand relationship. Having the results of these studies in mind, we will analyze supply and demand in more detail in subsequent studies, and we will certainly pay attention to the segmentation of supply and demand curves. Our research covered the EU countries, but it may be interesting to compare the analyses conducted for other groups of countries, e.g., Asian countries or highly developed countries compared with economically less-developed countries. Forecasts projected for a longer time horizon may also be interesting. The topic of the influence of COVID-19 on various spheres of economic and social life will certainly be both current and attractive for researchers in the coming years.

Author Contributions: Conceptualization, I.D. (Izabela Dembińska), A.B., K.S.-D., I.D. (Irena Dul), A.K., and G.I.; methodology, A.B.; software, A.B.; validation, Izabela Dembińska, A.B., and K.S.-D.; formal analysis, I.D. (Izabela Dembińska), A.B., K.S.-D., I.D. (Irena Dul), A.K., and G.I.; investigation, I.D. (Izabela Dembińska), A.B., K.S.-D., I.D. (Irena Dul), A.K., and G.I.; resources, I.D. (Izabela Dembińska), A.B., K.S.-D., I.D. (Irena Dul), A.K., and G.I.; data curation, A.B.; writing—original draft preparation, I.D. (Izabela Dembińska), A.B., K.S.-D., I.D. (Irena Dul), A.K., and G.I.; writing—review and editing, I.D. (Izabela Dembińska), A.B., K.S.-D., A.K., and G.I.; visualization, I.D. (Izabela Dembińska), A.B., and K.S.-D.; supervision, I.D. (Izabela Dembińska) and G.I.; project administration, I.D. (Izabela Dembińska) and K.S.-D.; funding acquisition, A.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Junior, P.N.A.; Melo, I.C.; Santos, R.D.M.; da Rocha, F.V.; Caixeta-Filho, J.V. How did COVID-19 affect green-fuel supply chain?-A performance analysis of Brazilian ethanol sector. *Res. Transp. Econ.* **2022**, *93*, 101137. [CrossRef]
2. Norouzi, N. Post-COVID-19 and globalization of oil and natural gas trade: Challenges, opportunities, lessons, regulations, and strategies. *Int. J. Energy Res.* **2021**, *45*, 14338–14356. [CrossRef] [PubMed]
3. Gürbüz, H.; Şöhret, Y.; Ekici, S. Evaluating effects of the COVID-19 pandemic period on energy consumption and enviro-economic indicators of Turkish road transportation. *Energy Sources Part A Recover. Util. Environ. Eff.* **2021**, 1–13. [CrossRef]
4. Smith, L.V.; Tarui, N.; Yamagata, T. Assessing the impact of COVID-19 on global fossil fuel consumption and CO_2 emissions. *Energy Econ.* **2021**, *97*, 105170. [CrossRef] [PubMed]
5. FuelsEurope. STATISTICAL REPORT. 2021. Available online: www.fuelseurope.eu (accessed on 21 July 2022).
6. Dziembała, M.; Kłos, A. The COVID-19 Pandemic and the European Union Economy–Counter-Crisis Instruments and Implications for the EU Budget and Its Member States. *Przegląd Europejski* **2021**, *1*, 81–98. [CrossRef]
7. Malliet, P.; Reynès, F.; Landa, G.; Hamdi-Cherif, M.; Saussay, A. Assessing Short-Term and Long-Term Economic and Environmental Effects of the COVID-19 Crisis in France. *Environ. Resour. Econ.* **2020**, *76*, 867–883. [CrossRef]
8. Wan, D.; Xue, R.; Linnenluecke, M.; Tian, J.; Shan, Y. The impact of investor attention during COVID-19 on investment in clean energy versus fossil fuel firms. *Finance Res. Lett.* **2021**, *43*, 101955. [CrossRef]
9. Yahya, F.; Shaohua, Z.; Waqas, M.; Xiong, Z. COVID-Induced Investor Sentiments and Market Reaction under Extreme Meteorological Conditions: Evidence from Clean Energy Sector of Asia-Pacific. *Probl. Ekorozwoju* **2021**, *16*, 7–15. [CrossRef]
10. Dembińska, I.; Kauf, S.; Tłuczak, A.; Szopik-Depczyńska, K.; Marzantowicz, Ł.; Ioppolo, G. The impact of space development structure on the level of ecological footprint-Shift share analysis for European Union countries. *Sci. Total Environ.* **2022**, *851*, 157936. [CrossRef]
11. Jóźwik, B.; Gruszecko, L. Impact of the COVID-19 pandemic on environmental degradation. Theoretical considerations based on the environmental Kuznets curve. *Przegląd Prawno-Ekon.* **2020**, *51*, 23–37. [CrossRef]
12. Tloczynski, D.; Wach-Kloskowska, M.; Susmarski, S. The Impact of COVID-19 on the Aviation Fuel Supply Chain in the Face of Changes in Air Traffic Service: Case Study of one of the Polish Airports. *Eur. Res. Stud. J.* **2021**, *24*, 623–633. [CrossRef]
13. Butt, A.S. Supply chains and COVID-19: Impacts, countermeasures and post-COVID-19 era. *Int. J. Logist. Manag.* **2021**. [CrossRef]

14. Duong, A.T.B.; Vo, V.X.; Carvalho, M.D.S.; Sampaio, P.; Truong, H.Q. Risks and supply chain performance: Globalization and COVID-19 perspectives. *Int. J. Prod. Perform. Manag.* **2022**. [CrossRef]
15. Chenarides, L.; Manfredo, M.; Richards, T.J. COVID-19 and Food Supply Chains. *Appl. Econ. Perspect. Policy* **2020**, *43*, 270–279. [CrossRef]
16. Rejeb, A.; Rejeb, K.; Keogh, J.G. COVID-19 and the food chain? Impacts and future research trends. *Sci. J. Logist.* **2020**, *16*, 475–485. [CrossRef]
17. Karwasra, K.; Soni, G.; Mangla, S.K.; Kazancoglu, Y. Assessing dairy supply chain vulnerability during the COVID-19 pandemic. *Int. J. Logist. Res. Appl.* **2021**, 1–19. [CrossRef]
18. Gray, R.S.; Torshizi, M. Update to agriculture, transportation, and the COVID-19 crisis. *J. Agric. Econ.* **2021**, *69*, 281–289. [CrossRef]
19. Francis, J.R. COVID-19: Implications for Supply Chain Management. *Front. Health Serv. Manag.* **2020**, *37*, 33–38. [CrossRef]
20. Szpilko, D.; Bazydło, D.; Bondar, E. The impact of the COVID-19 pandemic on the scope and quality of courier services. Results of a preliminary study. *J. Mark. Mark. Stud.* **2021**, *2021*, 10–22. [CrossRef]
21. Małecka, E. Impact of the COVID-19 pandemic on the Polish railway sector. *Acta Iuris Stetin.* **2021**, *34*, 75–89. [CrossRef]
22. Lubosz, A. The impact of COVID-19 on the behavior of miners in a selected hard coal mine. Support systems in production engineering. Energy and Mining–perspectives for sustainable development. *Sci. J. Syst. Wspomagania* **2020**, *9*. Available online: http://www.stegroup.pl/attachments/category/71/10.pdf (accessed on 20 July 2022).
23. Available online: https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=DSP_GLOSSARY_NOM_DTL_VIEW&StrNom=CODED2&StrLanguageCode=EN&IntKey=16509635&RdoSearch=CONTAIN&TxtSearch=101121&CboTheme=16713664&IntCurrentPage=1 (accessed on 20 July 2022).
24. Available online: https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=DSP_GLOSSARY_NOM_DTL_VIEW&StrNom=CODED2&StrLanguageCode=EN&IntKey=16468985&RdoSearch=&TxtSearch=&CboTheme=&IsTer=&ter_valid=0&IntCurrentPage=2 (accessed on 20 July 2022).
25. Available online: https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=DSP_GLOSSARY_NOM_DTL_VIEW&StrNom=CODED2&StrLanguageCode=EN&IntKey=33013371&RdoSearch=BEGIN&TxtSearch=Biogas&CboTheme=&IsTer=&ter_valid=0&IntCurrentPage=1 (accessed on 20 July 2022).
26. Available online: https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=DSP_GLOSSARY_NOM_DTL_VIEW&StrNom=CODED2&StrLanguageCode=EN&IntKey=16416285&RdoSearch=&TxtSearch=&CboTheme=&IsTer=&ter_valid=0&IntCurrentPage=1 (accessed on 20 July 2022).
27. Kovačević, S.; Rebić, M.; Kurušić, D. The Impact of the COVID-19 Pandemic on the Labor Market of Bosnia and Herzegovina: Application of the Exponential Equalization Methods. Researching Economic Development and Entrepreneurship in Transition Economies, Geopolitics and the Political Economy of Conflict in the Balkans and the Eastern Mediterranean: Refugees, Energy Sector and Prospects for the Future. 2021, pp. 116–119. Available online: https://www.redete.org/assets/content/conf-prog/conf-proceedings-2021.pdf#page=106 (accessed on 20 July 2022).
28. Üyesi, Ö.; Orkun Oralpp, I. Comparison of The Winters' Seasonality Exponential Smoothing Method With The Pegels' Classification: Forecasting of Turkey's Economic Growth Rates. Anadolu Üniversitesi Sosyal Bilimler Dergisi. Volume 19, pp. 281–284. Available online: https://dergipark.org.tr/en/download/article-file/828959 (accessed on 20 July 2022).
29. Ostertagova, E.; Ostertag, O. The Simple Exponential Smoothing Model. In Proceedings of the Modelling of Mechanical and Mechatronic Systems 2011, Košice, Slovakia, 20–22 September 2011.
30. Ostertagova, E.; Ostertag, O. Forecasting Using Simple Exponential Smoothing Method. *Acta Electrotech. Et Inform.* **2012**, *12*, 62–66. [CrossRef]
31. Montgomery, D.C.; Gardiner, J.S.; Johnson, L.A. Forecasting & Time Series Analysis. *J. Oper. Res. Soc.* **1978**, *29*, 618. [CrossRef]
32. Brown, R.G.; Meyer, R.F. The Fundamental Theorem of Exponential Smoothing. *Oper. Res.* **1961**, *9*, 673–685. [CrossRef]
33. Billah, B.; King, M.L.; Snyder, R.; Koehler, A.B. Exponential smoothing model selection for forecasting. *Int. J. Forecast.* **2006**, *22*, 239–247. [CrossRef]
34. Barczak, A.; Dembińska, I.; Rozmus, D.; Szopik-Depczyńska, K. The Impact of COVID-19 Pandemic on Air Transport Passenger Markets-Implications for Selected EU Airports Based on Time Series Models Analysis. *Sustainability* **2022**, *14*, 4345. [CrossRef]
35. WHO. *Coronavirus Disease 2019 (COVID-19)*; Situation Report–39; WHO: Geneva, Switzerland, 2019; Available online: https://apps.who.int/iris/handle/10665/331350 (accessed on 15 August 2022).
36. Available online: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-theyhappen (accessed on 15 August 2022).
37. Zalecenie Rady (UE) 2020/912 z Dnia 30 Czerwca 2020 r. w Sprawie Tymczasowego Ograniczenia Innych niż Niezbędne Podróży do UE oraz Ewentualnego Zniesienia Takiego Ograniczenia. Dz.U.UE.L.2020.208I.1. Available online: https://sip.lex.pl/akty-prawne/dzienniki-UE/zalecenie-2020-912-w-sprawie-tymczasowego-ograniczenia-innych-niz-niezbedne-69335838 (accessed on 15 August 2022).
38. Council Recommendation (EU) 2020/912 of 30 June 2020 on the Temporary Restriction on Non-Essential Travel into the EU and the Possible Lifting of such Restriction. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32020H0912&from=PL (accessed on 15 August 2022).

39. Prawa Pasażerów Lotniczych w Czasie Pandemii COVID-19–Pomimo Wysiłków Podejmowanych Przez Komisję Nie Zapewniono Ochrony Najważniejszych Praw. *Europejski Trybunał Obrachunkowy*. 2021. Available online: https://www.eca.europa.eu/Lists/ECADocuments/SR21_15/SR_passenger-rights_covid_PL.pdf (accessed on 15 August 2022).
40. Air Passenger Numbers to Recover in 2024. 1 March 2022. Available online: https://www.iata.org/en/pressroom/2022-releases/2022-03-01-01/ (accessed on 20 July 2022).
41. Dembińska, I. Potrzeby i preferencje w wyznaczaniu popytu na usługi transportowe–rozważania teoretyczne. *Zesz. Nauk. Probl. Transp. I Logistyki* **2011**, *14*, 9–29.
42. E-Commerce in the Time of COVID-19. 7 October 2020. Available online: https://www.oecd.org/coronavirus/policy-responses/e-commerce-in-the-time-of-covid-19-3a2b78e8/ (accessed on 15 August 2022).
43. Marzantowicz, Ł.; Dembińska, I. Introduction to the research of uncertainty in logistics management. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *568*, 012044. Available online: https://iopscience.iop.org/article/10.1088/1757-899X/568/1/012044/meta (accessed on 19 August 2022). [CrossRef]
44. Barczak, A.; Dembinska, I.; Marzantowicz, L.; Nowicka, K.; Szopik-Depczynska, K.; Rostkowski, T. The Impact of Unpredictable Factors on the Uncertainty's Structure in the Management of Logistics Processes. *Eur. Res. Stud. J.* **2020**, *XXIII*, 186–200. [CrossRef]

energies

MDPI

Review

Digitalisation of Enterprises in the Energy Sector: Drivers—Business Models—Prospective Directions of Changes

Barbara Siuta-Tokarska *, Sylwia Kruk, Paweł Krzemiński, Agnieszka Thier and Katarzyna Żmija

Department of Economics and Organization of Enterprises, Institute of Computer Science, Accounting and Controlling, Cracow University of Economics, 31-510 Krakow, Poland
* Correspondence: siutab@uek.krakow.pl

Abstract: The energy sector has been a pioneer in the use of information and communication technologies for many years, and has undergone enormous changes in recent years as a result of the transition resulting from the fourth industrial revolution. In the paper, we examine and analyse relevant studies and their findings in order to show the current status of research on three selected aspects of digitalisation in energy sector enterprises. The paper sheds light on the diverse drivers influencing the digitalisation processes of energy sector companies. It also provides an overview of business models that are or will soon be implemented in the energy sector thanks to opportunities offered by digitalisation in response to observed trends in the energy market. Finally, it illustrates open research challenges and future dilemmas related to various aspects of energy sector digitalisation. The paper was prepared using the critical literature review method. It covers a large volume of the most recent and relevant literature referring to the three major research areas mentioned above. The literature review allowed us to identify the drivers influencing the digitalisation of energy companies and distinguish between those specific to this sector and those relating to all businesses as a part of the more general phenomena of Industry 4.0 and Industry 5.0. We also show how the digitalisation-based business model innovation presented in the literature empowers new energy producers and consumers through business models. We have also identified the most frequently indicated challenges and dilemmas in the digitalisation of energy companies related to the risk of the destabilisation of the energy market due to decentralisation, new requirements placed on the competences of energy sector workers, the new culture of interaction between energy suppliers and consumers, and the digital security of data used in the energy system.

Keywords: digitalisation; drivers; business models; energy sector; changes

Citation: Siuta-Tokarska, B.; Kruk, S.; Krzemiński, P.; Thier, A.; Żmija, K. Digitalisation of Enterprises in the Energy Sector: Drivers—Business Models—Prospective Directions of Changes. *Energies* **2022**, *15*, 8962. https://doi.org/10.3390/en15238962

Academic Editor: Jamie W.G. Turner

Received: 8 October 2022
Accepted: 16 November 2022
Published: 27 November 2022

1. Introduction

The problem of the digitalisation of firms is one of the multifaceted and multi-threaded issues which, in the context of the contemporary economy, based on knowledge and modern technologies, are an important and worthwhile discussion. Energy sector companies undergoing digitalisation are strategic entities in the economy, as the energy efficiency improvements occurring with their participation are part of the sustainable development policies of Europe and the world. Therefore, the inclusion of the two above-mentioned areas of analysis is an expression of the scientific and research inquisitiveness of the paper's authors, being part of strategic management.

In this research paper, reference is first made to basic issues such as an explanation of the terms 'digitalisation of enterprises' and 'enterprise 2.0 and 3.0', followed by a review of the literature on the drivers and business models of energy sector companies undergoing digitalisation processes. And thus the bases were created towards the linear, time-based approach towards the directions of changes in light of the emerging challenges and dilemmas in their activities. In the last part of the paper, based on logic and lateral thinking, the above-mentioned components are combined, presenting an attempt to answer the research questions posed in this Introduction.

It should be noted that in the literature on the subject, the term 'digitalisation' does not have one commonly used definition. In the narrow sense, digitalisation is the processing of analogue data into digital form, but in the broader sense, it is a multi-stage process: the identification and selection of documents (information, knowledge), their preparation and ordering, collecting basic metadata, digital conversion, quality control of copies and metadata, providing the user with access to digital documents, the maintenance of digital copies and metadata, backup copies and planning for the future. However, as it applies to firms, this concept is understood as the use of digital technologies related to the configuration of their business models to ensure new opportunities to generate value within the organisation.

As A. Manterys [1] emphasises, the multitude of realities in which human activities take place, is the constellation of different arrangements and orderings. For the traditional market, a specific dualism can be seen, which, however, is not reflected in the virtual market, which requires analysis in different categories. It should be mentioned here that enterprises, which are market entities, have undergone a kind of evolution (Figure 1).

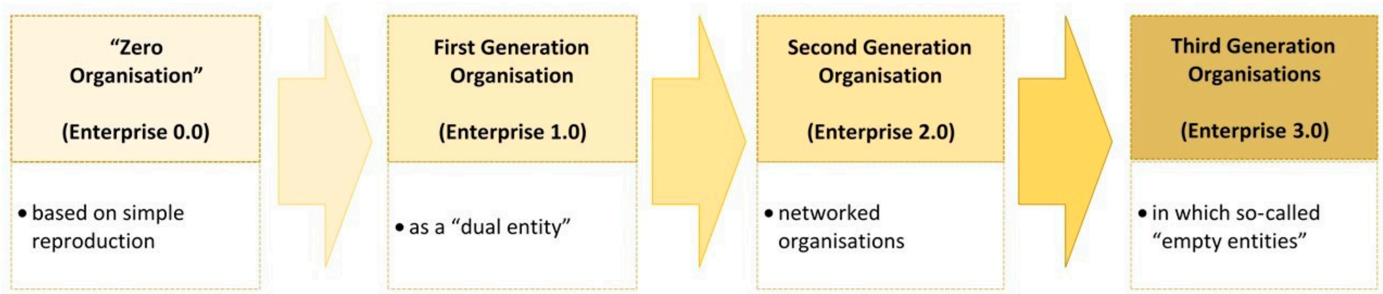


Figure 1. Evolution of market entities. Own-study based on [2] (pp. 21–22), [3,4], [5] (p. 33), [6,7].

This evolution included successive stages, namely [2] (p. 21):

- starting with so-called "zero organisation", based on simple reproduction (e.g., family farm of an "original" farmer or hunter);
- through the first-generation organisation, as a dual entity, functioning according to the firm- the environment principle;
- through second-generation firms, i.e., 2.0 (networked organisations), using in their operations collaborative technologies such as web services, P2P networking, collective intelligence, social networks, blogs, RSS feeds, wikis and mash-ups [3,4], [5] (p. 33);
- ending with third-generation organisations (enterprise 3.0) in which so-called "empty entities" exist, both inside and in the environment of such entities. 3.0 Enterprises are based on a flow arrangement, i.e., 'being in the flow', where values for and from the customer are composed on the basis of the creation and annihilation (or at least slowing down of transfers) of information and knowledge flow [6,7].

We agree with D.J. Hołodnik and K. Perechuda that networking breaks the traditional dual arrangements, such as "profit-loss, effective-ineffective, good-evil" [2] (p. 22). Of course, this does not mean that there are none, but the boundaries between them are slowly blurring, which is influenced by asymmetry and the excess of information (particularly tacit information) between corporations and skilfully dosed "information junk" for the masses (customers and consumers). The confusion and disorientation of an average customer/consumer in the context of the excess of information, in the absence of appropriate tools to process them, forces them to search for specialists who are able to offer them adequate digital services, both information and process-service ones, being part of the characteristics of 2.0 enterprises [8].

In contrast to 2.0 enterprises, the next generation is de-networked, de-empowered enterprises, based on the humanistic paradigm, which is the context of the density of information, knowledge, technological, capital and other densities of contemporary corporations find their place to operate where further network cooperation is not possible—corporations reach the so-called Break-Event-Point of their networking process. However, the management of 3.0 enterprises requires totally new managerial skills, as well as the adoption of a new development perspective [9] (p. 172), for which, however, the majority of modern businesses are not ready yet. Consequently, we can still observe the creation and development of strategies characteristic of 2.0 enterprises [10].

The functioning conditions of 2.0 enterprises focus attention on strategic risk, competition strategy, as well as social sensitivity [11]. The analysis of the critical factors of their development is, in this aspect, an element of the strategy the formulation and adoption of which depends on the position of the enterprise in the network, its network capacity (value creation in the form of a network advantage, relational abilities, as the network participant which favours capturing values [12].

As D.A. Johnston, M. Wade and R. McClean [13] rightly observe, adaptation to the conditions of e-business functioning may be expressed in tangible financial results. However, profits gained may be different depending on the region, type of industry/business sector, as well as the company size class. It can therefore be assumed a priori that there are specific differences in digitalisation:

- enterprises functioning in markets with developed digital structures (developed countries) compared to those which operate in developing countries or in third-world countries;
- industrial firms in comparison with purely commercial or service ones;
- large corporations compared to SME sector companies (in terms of time, scope, finance, etc.).

As P. Depaoli, S. Za and E. Scornavacca [14] indicate, "digital business solutions are commonly adopted with the goal of improving firms' performance". It results from the fact that investment in technologies is one of the key decisions in the context of enterprise strategic operations, transforming its organisational activities, as well as deeply penetrating its broadly understood competitiveness and development. It was also a premise to undertake theoretical research based on the literature of the subject.

2. The Concept of Research and Its Methodology

The aim of this paper is to review the existing research on the drivers and business models, as well as prospective directions of changes in the energy sector enterprises in the context of their digitalisation. Due to the revealed cognitive gaps, the authors of the paper formulated the following research questions:

1. Among the drivers of enterprise digitalisation, can we identify those which are universal for all businesses and those which are characteristic of only energy sector firms?
2. Which innovative business models in the energy industry are being or will be actively implemented in the near future due to digitalisation as a response to current trends in the energy market?
3. What prospective directions of changes will determine the paths of development for the energy sector enterprises in the nearest future?

We selected keywords from three broad areas, such as drivers, business models and prospective directions of changes in the enterprises of the energy sector to identify research papers that would help to answer the above-mentioned research questions. We searched using the title, keywords and abstract fields according to the searching database. We used Scopus, Google Scholar, Science Direct and Emerald databases as these provided papers that were the most relevant to our research. The time range of the cited scientific sources included, in the vast majority, publications from the last 5 years concerning enterprises in the energy sector.

The methodology of the theoretical research undertaken, in terms of the literature review, was selected in such a way as to enable an objective and structured approach to the study of factors, or more precisely, determinants (drivers), business models and prospective directions of changes in the field of the studied phenomena related to the digitalisation of energy sector enterprises. Therefore, the following research methods were adopted, broken down into research stages:

1. Generating information—based on keywords searched in scientific databases;
2. Collecting and selecting information (scientific publications);
3. Coding based on the thematic criterion (digitalisation of energy sector enterprises) and date criterion (the date of articles, monographs and other scientific studies publication);
4. Organising information by research areas, i.e., in terms of factors, and in particular, determinants (drivers), business models and prospective directions of changes, as well as detailed issues in these areas;
5. Analysing and drawing conclusions.

Taking into account the type of research, it should be emphasized:

- the theoretical and cognitive nature of the research undertaken;
- the scope of theoretical, thematic considerations focused on the digitalisation of enterprises in the energy sector;
- types of research methods used, referring to scientific research methods in the field of empirical sciences;
- the type of reasoning adopted, i.e., deductive reasoning, based on the compatible direction with the result.

As a result, the adopted research methodology allowed for the total compilation of 93 bibliographic items, while the research limitations apply to the adopted four databases indicated above. However, it should be emphasised that the selection of these databases was dictated by the citation rate of their publications and recognition in the scientific community.

The purpose of adopting the research methodology defined in this way was to systematize and also to synthesize the current state of knowledge in this field, and after proper research, it should allow [confirmation or contradiction] and/or extension of the answers to the research questions posed. Thus, the authors' contribution, resulting from the conducted literature research, concerns the systematization and synthetic presentation of the current state of knowledge in the field of the digitalisation of energy sector enterprises, taking into account the detailed issues of factors, including determinants (drivers), business models and prospective directions of changes.

The added value of this paper is the attempt to investigate possibly the most comprehensive appraisal, based on domestic and foreign literature, in the area of social sciences at the scope of relationships between the drivers of digitalisation, new innovative business models of the energy sector enterprises emerging as a result of adapting to changing operating conditions, made possible to introduce digital technologies and the prospective directions of their changes in light of contemporary challenges and dilemmas in their operations.

3. The Drivers of the Digitalisation in the Energy Sector Enterprises

Beginning in the 1960s, common regulations concerning the activities of energy sector enterprises operating in the EU market began to be introduced. They were included in the "founding treaties": the establishment of EURATOM and the European Coal and Steel Community, followed by the establishment of the International Energy Agency in 1974. In turn, the Single European Act (1986) contributed to research on the European energy sector. The first directives on the liberalization of the energy market were adopted in 1996 (First Energy Package). The Energy Charter Treaty (1998) established a framework for energy investment, trade in energy commodities and energy distribution. The second energy package was adopted in 2003 and the third in 2009, which was related to the further liberalization of the electricity and gas markets, and in 2009 the fourth energy package was introduced, including the European Union Agency for the Cooperation of Energy Regulators (ACER). The fifth energy package (Delivering the European Green Deal) was published in 2021.

These requirements have become a challenge not only for energy sector companies because the implementation of the Common Energy Market has a direct impact on all areas of life. As A. Czech notes, the process of consolidating the European Member States' markets into one competitive energy market is complex and lengthy. It requires a number of strategic political decisions, including energy liberalization and the adoption of sectoral legislation [15]. The activity of enterprises in the energy sector is determined by the heterogeneous energy infrastructure among EU Member States, as well as the frequent differences in legal environments and institutional and administrative systems.

Some EU countries are characterized by modern and developed electricity and gas infrastructure, while others are clearly lagging behind in this respect. Europe's lack of energy self-sufficiency and import dependence is becoming more and more apparent. According to The Dependency Rate on Energy, the import of energy consumed by EU member states has increased from 47% in 2019 to 53% in 2022 [16]. Moreover, there are large variations between Member States, with energy dependency rate ranges from over 95% for Malta, Luxembourg, and Cyprus to below 15% for Estonia and Denmark [16]. This proves the existing heterogeneity and limited intra-market possibilities of meeting the demand for energy.

As noted by A. Carfora, R.V. Pansini and G. Scandurra, the current direction of EU activities in the field of energy is to reduce energy dependence, which is to be achieved by improving the efficiency and maximum use of domestic energy sources as well as the promotion of renewable energy sources (RES) [16]. Actions taken should be implemented in accordance with the disclosed need to ensure more stable and safe supplies, including increasing the use of renewable energy sources, while reducing greenhouse gas emissions. For these reasons, efforts have recently been focused on ensuring energy security taking into account the principles of sustainable development, thus becoming one of the priorities in defining the new energy policy framework in the EU [17] (pp. 155–163), [18] (pp. 127–136). The process of changes related to the consolidation, research, liberalization and common energy policy in the energy market of the European Union countries is presented in Figure 2.

Figure 2. Changes related to the research, liberalization, consolidation and common energy policy in the energy market of European Union countries. Own-study based on [15] (pp. 251–262), [17] (pp. 155–163), [18] (pp. 127–136).

Thus, the activity of energy sector enterprises is very strongly related to socioeconomic conditions. There is an increasing demand for electricity against the backdrop of a decline in non-renewable energy resources. Therefore, this macroeconomic factor should be considered significant and determining the development of enterprises in this sector.

The adopted direction of development, related to the use of renewable energy sources in the operation of the energy sector—in the context of global socio-economic conditions—seems to be correct [19]. Lutz, Fischer, Newig and Lang list 19 driving factors of renewable energy implementation processes [20]. They have all been grouped into the following four clusters:

1. Planning and process;
2. Exchange and participation;
3. Actors and networks;
4. Economic circumstances.

As shown in the above studies, formal networks emerge as a strong driving factor in the studied regions. Regions where formal networks are important see the positive impact of renewable energy use on the regional economy [20]. Therefore, it can be assumed that networking related to the digitalisation processes of energy sector enterprises is an important factor in their development in the context of plans for the use of renewable energy sources. This corresponds to the idea of sustainable development in relation to natural capital.

Due to the complexity of the research topic undertaken, it is worth paying attention to the closely related terms "condition" and "factor". The ability to distinguish between static and dynamic variables in the context of the development of enterprises affects the correct determination of the components of this development and the ability to properly prioritize them in the context of setting development goals.

"Conditions" are a feature or set of features on which the existence of something depends, and a situation prevailing in some area (location, circumstances) in which something happens [21]. In turn, the term "factor" should be understood as the cause of a specific phenomenon, and something that has an impact on the observed phenomenon, actions taken or the existing situation [22]. The word "factor" comes from the concept of action (lat. *facere* = to do) and is one of its elements—the cause [23]. An activity is a form of the active human relation to reality or a process aimed at achieving a goal, the structure of which is shaped depending on the existing conditions [24]. As A. Kaleta notes, the two concepts analyzed above are closely related, particularly regarding the development of an enterprise, the relations between the "condition" and the "factor" are indicated [25]. The literature on the subject emphasizes that "development conditions" have a less direct impact than "development factors", as they are of a potential nature. They may be present in a given place, time and area (legal, economic, social, etc.), they may be favourable and unfavourable, or they may be completely absent. Thus, the existence of appropriate conditions creates the possibility of emergence and development [26]. The disclosure of the development condition contributes to the implementation of certain activities. In turn, the factor triggers some process of action, which is then confronted with the identified conditions. Thus, the factor is an active attitude to reality. The condition, on the other hand, may be of a natural, technical or social nature [23]. Hence, it is assumed that the conditions of development are generally static and are recognized as resources. On the other hand, the factors are dynamic and are treated as streams [27]. In terms of economic capital, the term "conditions", understood as a set of more or less favourable circumstances (conditions) enabling or limiting development, seems to be a more appropriate term than a "condition".

According to S. Chomątowski, conditions (for economic capital these are economic conditions) and factors, including drivers of enterprise development can be understood as what is related to the development of the enterprise and influences this development directly or indirectly. In other words, the conditions for the development of an enterprise are permanent or shorter-lasting possibilities, existing in a given place and time. They include all the opportunities and threats that may favor or limit the development of the enterprise [27]. The conditions of development have a real and material dimension. Their discovery and use contribute to the development of the enterprise, thus becoming its drivers [28].

Returning to today's challenges related to the implementation of sustainable development, three basic conditions useful in the analysis and evaluation of the development of energy sector entities should be indicated. They are part of the "3 Ds of Energy" based on digitalisation, decentralization and decarbonization. These are conditions and factors related to economic, social and natural capital.

Experts from the International Energy Agency [29] (pp. 18–20) indicate that the global demand for electricity will increase by about 2–3% annually [30]. Throughout 2021, global energy demand and emissions increased by 5% compared to 2020, almost reaching pre-COVID-19 levels (~33 Gt energy-related CO_2 equivalent) [30]. As energy consumption increases, so too will greenhouse gas emissions. This could lead to an increase in global temperature of 4–6 °C by 2030 [31]. According to industry analyses, even if all countries with net-zero commitments deliver on their aspirations, global warming is projected to reach 1.7 °C by 2100 [30]. Such a forecast determines further planning of activities in this regard.

The mentioned conditions and factors are closely related. The activity of enterprises in the energy sector is conditioned by the existence of demand for energy by social capital. This is also an important determinant of how much, how and when energy will be used. The process of obtaining electricity and heat, in turn, involves the use of renewable and non-renewable resources that belong to natural capital. Finally, in order for energy to be delivered, economic capital is needed for energy production and transmission infrastructure.

The development of technology determines the technical capabilities of energy production and transmission infrastructure, as well as the degree of its modernity, reliability and efficiency. It is on the basis of the above-mentioned characteristics that the assessment of this infrastructure is made. The digitalisation process of energy sector enterprises has a direct and indirect impact on these characteristics.

The researchers claim that the energy industry can increase energy efficiency through various changes leading to the integration of individual energy companies and information communication technologies (ICT) supporting processes related to energy generation, transmission and delivery [32]. Therefore, digitalisation plays a key role in the implementation of the new model of the 3 Ds of Energy development. Effective digitalisation will allow the development of more and more advanced technologies enabling the diversified production of energy from decentralized renewable sources. This will make possible the switch from non-renewable sources in the form of coal or crude oil to renewable sources.

Park, Cho & Heo distinguish three main entities which will have a strong influence on digitalisation: (1) energy policymakers, (2) researchers and (3) market participants [33]. Based on empirical research by You & Yi, it has been shown that "self-transcendence knowledge" is very important and critical in the knowledge management and promoting energy companies to react quickly to changes and challenges related to digitalisation [32]. The policy of transforming the energy sector adopted in the EU assumes transferring energy production to renewable sources, reducing the emission intensity of the economy and increasing energy efficiency. The implementation of these plans is to ensure energy and environmental security, enable constant civil development, and the creation of low-emission, highly effective energy based on renewable energy sources. In this respect, digitalisation is treated as a tool for the implementation and development of a new energy policy. As A. Kucharska notes, "digitalisation is an essential element of energy infrastructure management, smart grids and smart meters. It allows better equality of energy distribution, which is a factor in combating energy poverty" [34]. One should be aware that the digitalisation of the energy sector is not a "cure for all diseases" in this sector and is associated with specific threats, which will be presented below. However, digitalisation should be seen as an effective tool for more effective management of the production, distribution and storage of electricity and heat. Digitalisation is a significant factor in the development of enterprises in the energy sector, which is also part of the concept of sustainable socio-economic development.

The above-mentioned drivers in the digitalisation of energy sector enterprises are specific to this industry and fundamental to its development. They are related to the process of implementing the new energy policy based on the assumptions of the 3 Ds of Energy. There are also other drivers in the digitalisation of the activities of energy sector enterprises, which are also noticeable in other industries and result from the so-called digital transformation of business [35].

Both specific and general factors driving the development of the digital economy (digitalisation of activities) of energy sector enterprises as well as enterprises from other industries are presented in Table 1 ([29] (pp. 21–23), [35–37]).

Table 1. Specific and general factors in the digitalisation of energy enterprises.

Type of Drivers	Drivers
Specific drivers of digitalisation of energy enterprises	- The 3 Ds of Energy; - Transferring energy production to renewable sources, reducing the emission intensity of the economy and increasing energy efficiency; - Integration of individual energy companies and information communication technologies (ICT) supporting processes related to energy generation, transmission and delivery; - Development of management tools: intelligent energy transmission networks and smart meters as well as tools for controlling the entire energy system.
General drivers of digitalisation of energy enterprises and entities from other industries	- Internet of Things (IoT) and Internet of Everything (IoE); - Hyper-connectivity; - Greater effectiveness in reaching and contacting customers; - Cloud Computing Applications and Services; - Big Data Analytics (BDA) and Big-Data-as-a-Service (BDaaS); - Automation and Robotisation [29] (pp. 21–23); - Multi-Channel and Omni-Channel Models for the distribution of products and services.

Source: own-study based on [29] (pp. 21–23), [35–37].

The challenges and opportunities related to the above-mentioned factors, which refer straight to the energy sector include [38–40]:

- the implementation of Industrial Internet of Things solutions in electricity supply systems, based on a network of sensors monitoring energy demand, managing its transmission and storage;
- the use of Artificial Intelligence in order to optimize energy transmission and distribution;
- the use of blockchain technology to manage energy resources and logistics, which increases the operational efficiency of energy companies;
- the use of smart grids and models to monitor changes in energy demand and to respond autonomously to emerging changes through proper energy distribution;
- creating "Virtual Power Plants", which are a combination of decentralised units on the electricity grid coordinated by a common control system that allows them to dynamically plan and adjust production and to trade in the energy market at the lowest possible operating costs;
- the implementation of energy management systems integrating prosumers and consumers, able to optimize the production and consumption of energy coming from various sources, based on the use of smart meters or consumer IoT devices (mobile reporting applications);
- the use of digital modeling to design new and improve existing energy networks. The use of this tool will increase the operational efficiency of energy sector entities, allowing faster (compared to the solutions used so far) data analysis on the basis of

real energy networks to develop new investments and reducing the cost of designing new installations;
- the use of blockchain, which will increase the level of automation and security of transactions on the power grid, e.g., those involving the sale of micro volumes of energy between prosumers;
- building systems in the form of "digital twins", based on a real-time collaboration between a digital replica of a physical object and the object itself, enabling decisions referring to the optimisation of its operations.

Digitalisation in supply chain management, also in the energy sector, allows for the implementation of the most important efficiency criteria in the form of costs, time and service quality. It contributes to maximizing the effectiveness of customer service by delivering the right product (service) as quickly as possible and reducing the cost of service while ensuring high availability and reliability of the service (product) [41].

4. Business Models in Energy Sector Enterprises in the Context of Digitalisation

V. Akberdina and A. Osmonova note that the digital transformation in energy sector enterprises has been taking place in the world for many years [42,43]. As noted by J. Świątowiec-Szczepańska and B. Stępień, this sector pioneered the implementation of information and communication technologies and over the past few years it has undergone enormous changes as a result of changes related to the fourth industrial revolution [44]. Digitalisation in the energy sector is linked to the creation and use of computerized information and the processing of the huge amount of data that is generated along the energy supply chain. New digital technologies offer great opportunities to improve the efficiency of managing an advanced energy system: from infrastructure design, operation and maintenance, through energy production and transmission, to its consumption. Due to digitalisation in the energy sector, the necessary infrastructure and interfaces are created that enable the efficient functioning of operators and the intelligent and effective implementation of the processes they support because it enables cheaper, faster and better monitoring using "smarter" networks [45]. P.F. Borowski points out that, as research shows, digitalisation enables energy companies to reduce operating costs and improve efficiency, and additionally helps to extend the life of power plants by about 30% [46].

The most important global digital trends affecting the energy sector and selected concepts of innovative business models corresponding to them, are presented in Figure 3.

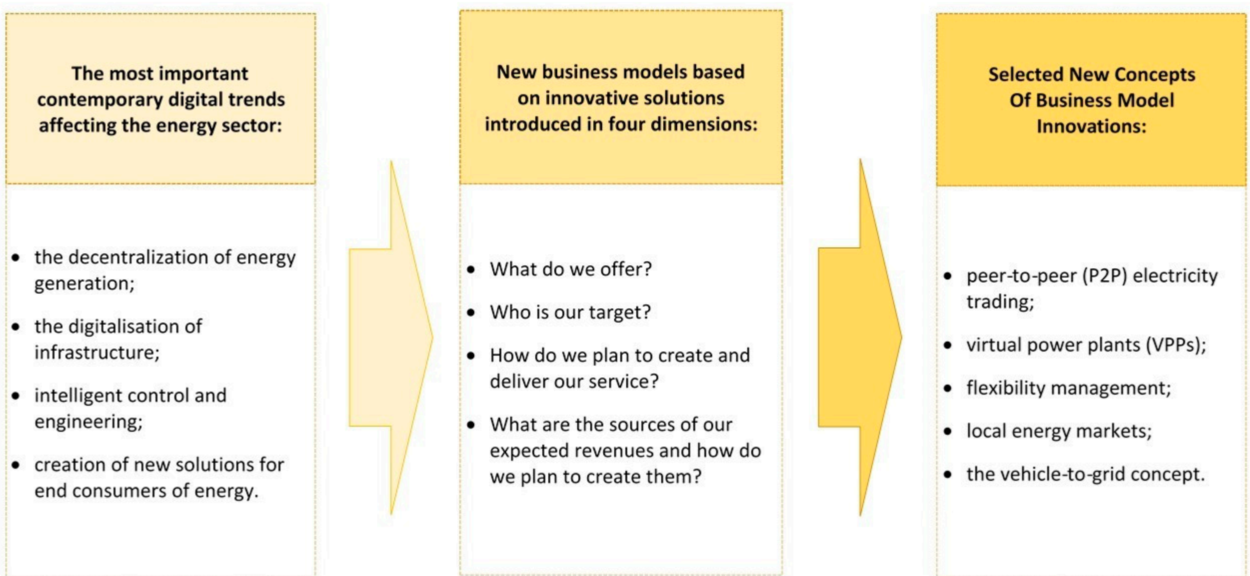


Figure 3. The main digital trends and the most popular business models observed in the energy sector practice in the 21st century [44,45,47–65].

Global digital trends makes energy sector companies look for effective methods of competing, shaping and implementing new strategies and business models, using them to an increasing extent in various types of innovation and cooperation networks. As rightly noted by J. Brzóska and M. Krannich, for energy companies, a significant factor influencing their strategic reorientation is also the energy and climate policies implemented in specific countries or a group of countries in a specific region [66]. Currently, the key area in the field of strategic management is to ensure that businesses have the capacity to implement quick and abrupt changes that affect the enterprise itself, including its strategy, structures, resources and processes, and its environment. For this reason, the ability to act quickly and flexibly in a turbulent, rapidly changing environment becomes very important. Research conducted by A. Kaleta, J. Radomska and L. Sołoducho-Pelc shows that in large enterprises, such as energy sector companies, innovation is related to strategic management, and this relationship is related to a strategic response to challenges [67]. According to A. Ates, P. Garengo, P. Cocca, and U. Bititci, large enterprises more often than SMEs design and implement formalized processes to manage operational and managerial activities. In the case of SMEs, the systems and processes related to decision-making and the management of the entire business are less structured [68].

The development of industrial strategies is often associated with the occurrence of conflict situations. Some of them, concerning opposing objectives such as, for example, increased production versus environmental impact, or increasing automation versus reducing employment, are very difficult to resolve. Improving productivity is important for wage growth, and at the same time, it is very often associated with the implementation of advanced technologies that reduce employee involvement. Developing countries often accept environmental issues because they want to counteract labour-saving technology [69].

Tensions related to the necessity to meet the needs of customers, the activities of competition and the level of costs result in the emergence of new methods, tools and theories in managing the development of the energy sector. At the same time, energy sector companies design and reformulate their business models, which is difficult in an unstable and complex environment [70]. S. Küfeoğlu, G. Liu, K. Anaya and M.G. Pollitt note that the newly adopted business models in the energy industry vary in terms of four business model dimensions [45]:

- Value Proposition, which refers to the way in which an organisation creates value for its customers;
- Targeted Customers, specifying to whom they are addressed;
- Value Creation (Value Delivery), determining how their service will be created and delivered;
- Value Capture (Revenue Model), relating to the sources of their expected revenues and how they plan to create them.

B. Fattouh, R. Poudineh and R. West note that their effective functioning requires flexible and systematically adapted development strategies [71].

A key driving factor in energy sector digitalisation is the increasingly distributed character of the electricity generation system, which opens up new business opportunities. The decentralization of power generation is part of the transformation based on the so-called 5 Ds (decentralization, digitalisation, decarbonization, democratization, and decreasing consumption), which are the driving forces of the current energy transition [72]. As noted by A. Hirsch, Y. Parag and J. Guerrero, the increasing use of renewable energy sources is playing a huge role in accelerating this trend [73]. S. Küfeoğlu, G. Liu, K. Anaya and M.G. Pollitt add that the development of renewable energy means that today energy is generated within the electricity distribution grid that includes many more nodes than ever before. The problem, however, is the intermittency of this production and the poor match of its supply to demand [45].

According to A. Idries, J. Krogstie and J. Rajasekharan, the decentralized energy means energy that is generated closer to the place where it is used. It is therefore not drawn from a large centralised power station that is part of the regional or national grid [74].

As rightly noted by J. Silvente, G.M. Kopanos, E.N. Pistikopoulos and A. Espuña, the local generation of energy reduces transmission losses that result from the long distance between production and consumption sites and decreases environmental degeneration as it lowers carbon emissions [75]. It also increases the security of supply for all consumers, as they do not use a single power source or depend on relatively few large and remotely located power plants [76]. A.M. Adil and Y. Ko point out, that energy decentralization has three configurations: distributed generation, micro-grids, and smart micro-grids [77]. The backbone of energy decentralization is distributed generation, which can be defined as "*generating plant connected directly to the grid at distribution level voltage or on the customer side of the meter*" [78,79].

As indicated by H. Khajeh, H. Laaksonen, A.S. Gazafroudi and M. Shafie-khah, decentralized energy is accompanied by the transformation towards a platform-based model, which is a good starting point for service innovation in the energy sector. As a result of this transition, various services will be provided by these platforms, thereby giving many stakeholders and actors the opportunity to benefit from them [80]. Digitalisation helps to better manage the network and congestion, helping to solve the problems of discontinuities related to the production of energy from renewable sources. It makes it possible to use digital platforms to respond to demand, Peer-to-Peer (P2P) energy and carbon credit trading [45]. K. Osmundsen notes that a crucial trend for the digital development of the energy sector is also transforming grid networks into smart grids, which are electricity networks able to process, control, and manage huge data flows [43,81].

As shown in Figure 3, changes important to the existing energy system include business model innovations based among others on the following concepts:

- peer-to-peer (P2P) electricity trading;
- virtual power plants (VPPs);
- flexibility management;
- local energy market;
- the vehicle-to-grid concept.

Irregular small-scale energy production and energy exchange between autonomous micro-grid prosumers [48] can be integrated into the energy system with low indirect costs thanks to P2P energy trading. Peer-to-peer (P2P) electricity trading is a new data-driven business model that is currently being tested in the energy sector [49]. Peer-to-peer (P2P) energy trading is essentially based on direct transactions between prosumers and consumers who trade energy with each other without the electricity supplier or retailer as an intermediary. The place of the intermediary is taken by a third-party digital platform, e.g., blockchain-based, which allows prosumers and consumers to interact directly and negotiate better prices for electricity, relative to the offer of a licensed supplier [50,51]. This type of energy trading can be facilitated by the digitalisation of the economy and by the use of advanced digital technologies such as Artificial Intelligence (AI) or Blockchain [45].

Artificial neural networks allow the analysis of information in an innovative manner. These are mathematical and computer models that imitate the work of neurons in the human brain, so they can analyse information and learn to generate proposed solutions. J. Świątowiec-Szczepańska and B. Stępień point out that their application is possible in many areas, and they are used at each stage of the energy value chain [44]:

- energy network design: to forecast energy demand and assess the reliability of generation equipment, in the automation of protection, and controlling of systems' overload in production and transmission;
- energy production: to prevent and optimise the equipment operating costs;
- transmission and sales: for automation of selecting the most cost-effective or strategic suppliers, dynamic differentiation and optimisation of energy prices according to seasonal trends in customer habits, billing automation, etc.

AI can be used to optimize energy storage and supply management, it has the potential of a predictive system and can be the basis for creating systems that respond to energy changes [52]. The consequence of AI managing energy transmission is Demand Response Models (intelligent networks supported by models of responding to changes in demand) enabling real-time monitoring of changes in energy demand and proper energy distribution [52].

Other digital technologies, such as blockchain, can improve the information flow process, document flow, property management, logistics and security of supply. Blockchain enables, through the controlled use of data, the management of the increasing complexity of the structure and networks of the energy sector and direct interaction between entities through comprehensive monitoring of energy flows at low costs [44]. The greatest benefits associated with the introduction of blockchain technology include the possibility of concluding direct transactions between energy suppliers and their customers. Blockchain technology solutions can also enable the sale of micro volumes of energy between prosumers [52]. Traditional energy trading faces problems such as single points of failure and privacy leakage. Therefore, efficient and transparent models are needed in this area. The advantages of blockchain technology include trust, security and decentralization. This technology maintains a distributed database, eliminating the need to involve third parties, improves economic efficiency, and reduces management costs [53] and ensures supply security by providing information on the origin of energy [44]. In addition, E. Mengelkamp et al. add that blockchain technology provides user-friendly applications that enable them to participate in making decisions about which technology they use to generate energy and who produces it [54].

One of the most reliable and efficient ways to ensure the efficiency, stability and competitiveness of distributed generation is the use of a business model based on the concept of a Virtual Power Plant (VPP). A VPP is a system integrating a few types of energy sources, which provide a reliable overall power supply. Virtual power plants can be described as decentralized energy management systems, which pool the capacity of different units: renewable and non-renewable ones, different storage devices and distributable loads, participating in the energy market and trading energy (and services) with the upstream network [55]. P. Asmus defines VPPs as "software systems, which remotely and automatically dispatch and optimize generation or demand side or storage resources in a single, secure Web-connected system" [56]. Through software innovation, VPPs use existing energy networks to tailor electricity supply and demand services to meet customer needs. This maximises value, both for the end customer and for the distribution company [56]. The VPP buys spare capacity from energy-producing entities and manages the power plant production according to the real-time sales demand. The produced energy is sold simultaneously on multiple markets—on the Power Exchange (PEx), on the balancing energy market and directly to end users. This business model allows small power plants to earn higher margins without incurring additional energy sales and balancing costs [57]. As noted by S. Baidya, V. Potdar, P.P. Ray and Ch. Nandi, the functional capabilities of virtual power plants are, therefore: (1) optimisation of network modes, (2) management of electricity consumption and (3) market management of the reserve capacity [58,59].

The dynamic development of renewable generation and distributed energy resources presents distribution systems with new operational challenges related to intermittency and uncertainty of supply. Addressing these challenges requires distribution system operators to introduce business models that enable more active and flexible management and system control. This results in a shift to a local approach in energy system management. P. Olivella-Rosell et al. point out that local Energy Markets (LEM), also known as micro-markets or local electricity markets [60], use online platforms and smart grid technologies as a means to integrate and coordinate Distributed Energy Resources (DER) at the distribution grid level [61]. According to S. Beattie, W.K. Chan, A. Wei and Z. Zhu, this is important, especially in relation to the local supply of spatially distributed renewable resources that cannot be directly controlled [62]. As noted by P. Olivella-Rosell, G. Viñals-Canal et al. studies show that with too small distribution networks, LEM can effectively improve social welfare compared to other, simpler solutions [60].

The possibility of implementing new business models is also seen in the development of V2G technology. Electric vehicles (EVs) can be classified in terms of their charging methods, energy storage mechanisms or energy sources. The increase in sales of electric vehicles is related to the need to increase the amount of available energy. In addition, the needs of charging electric vehicles result from the profiles of drivers and their mobility. All this affects the allocation of electric vehicle charging demand [63]. V2G technology creates added value for EV users and Distribution System Operators, as some specific services can be provided to the power grid. By connecting am EV to the grid, the bi-directional energy exchange is possible, from the power grid to the electric vehicle and the other way round, from the electric vehicle to the grid [64]. With the growing number of electric vehicles, these services can support the energy industry to better manage energy generation, its management and, ultimately, its consumption. Electricity management by consumers in the technology of two-way energy exchange is a new approach in terms of building a new power grid and the value of available power consumption [65]. As rightly noted by B. Mroczek and A. Kołodyńska, nowadays more and more attention is paid to the problems of network management. The popularity and effectiveness of V2G services among EV users will depend on the correct definition of electricity demand [65].

In conclusion, it should be stated that the business models introduced by energy sector enterprises are associated with the pressure resulting from the transformation towards the digital economy. In this context, the strategies that relate to gaining a privileged position in the industry are also changing. Changes in the energy sector are influenced by the acquisition of entities from the periphery of the energy sector or those that are still reserved for other products. This mainly refers to big data entities and enterprises using energy-based products [70]. R. Trzaska et al. emphasise the need to implement digital technologies in the energy sector due to their potential to increase efficiency, productivity, speed and security, as well as reduce costs. This becomes possible mainly thanks to the use of artificial intelligence, the development of advanced sensors for process monitoring and remote access in various organisational areas [70]. It is important to develop business models that are based on the real added value that distributed energy can bring to the entire energy system. This added value may be a solution that allow for real local real-time power balancing, which requires an advanced data ecosystem and algorithms for managing a distributed system. However, such business models require a number of innovations in many areas.

These factors emphasise the need to introduce digital solutions in the energy sector due to their potential to increase efficiency, productivity, speed, safety and cost reduction.

5. Challenges and Dilemmas of Energy Sector Enterprises Regarding Industry 4.0 and 5.0

The digital transformation of the energy sector is part of the more general current phenomena of Industry 4.0 and Industry 5.0. Moreover, this process is a component of shaping the information society and the implementation of the global plan of sustainable development [82] (pp. 283–294). It is important to distinguish between two ways of understanding the essence of the digitalisation of the energy industry. Firstly, it is the automation of existing engineering and business practices using digital technologies. Secondly, radical technological and civilizational change is associated with the transformation of the very structure of the industry and the emergence of new practices (*Digital transformation*). We will continue to talk about digitalisation in the latter sense [83]. The effects of digital transformation are shown in three projections: in the area of technology, business and culture [84]. Moreover, digitalisation affects the nature of the relationship between the above-mentioned areas (human–technology, human–business, and business–technology). The following opportunities offered by digital transformation can be listed:

- Increasing the efficiency, stability and security of the current energy system (application of mathematical models, digital twins, cloud solutions vs. hosting solutions, real-time control); increased precision in servicing systems and devices (3D-PLM-MES expertise); creating new forms of staff training (gamification, virtual and augmented reality technologies) [85,86];

- Lowering operating costs (OPEX) and capital expenditure (CAPEX); introducing new business models and forms of distribution (Energy Aggregator, Internet of Energy, Distributed Energies Resources) to meet the requirements of local energy markets;
- Integration of systems based on different renewable energy sources, e.g., solar power grid control depending on atmospheric changes, optimal adjustment of consumption to the applicable local tariffs (big data, smart grid) [86,87].

At the same time, the digitalisation of the energy sector is associated with new challenges and dilemmas concerning, inter alia, the risk of destabilisation of the energy market resulting from its decentralisation, new requirements for the qualifications of people employed in the energy sector, a new culture of the cooperation between energy suppliers and recipients and ensuring the digital security of data used in shaping a common energy system [82] (pp. 283–294). To a large extent, the above-mentioned dangers related to the digitalisation of the energy sphere are also specific to other areas of life where digital transformation takes place. Generally speaking, meeting new challenges and dilemmas is associated with finding a balanced dynamic relationship between the area of technology, business and culture, ensuring the free flow of information between these areas. Below, we will describe some of the difficulties accompanying the digital transformation of the energy sphere:

1. Risk of instability of electric networks—due to the inexorable increase in energy consumption, the decentralisation of its generation and the increase in the diversity of its sources, the risk of instability of electricity networks has increased, which was partly reflected in the winter blackout in Texas [88] and the summer blackout in Great Britain [89];
2. The need for close integration and information exchange within the energy branch—new methods of electricity distribution require good information exchange between the individual elements of the energy system, matching and close cooperation between the producer, distributor and consumer of electricity [86];
3. Increased requirements for cybersecurity—along with the rapid increase in the number of intellectual devices in automated systems and the exponential increase in the volume of information sent by them, the area susceptible to a possible attack by hackers has significantly expanded. Therefore, solutions guaranteeing digital security must reach a new qualitative level [86];
4. Increased requirements for the professional qualifications of operating personnel—in connection with the implementation of the new technologies mentioned above, the requirements for operating personnel (installation, tuning, scheduled maintenance, repairing) of power plants and other infrastructure in the energy sector are significantly increasing. Today, operating personnel must be familiar with technologies such as MAC address, IP address, VLAN, Cloud Computing control, IEC 61,850 protocol etc. [85];
5. Changing the thinking paradigm—a lack of trust in cloud computing infrastructure on the part of customers is still a frequent phenomenon. In their opinion, if something works well, there is no need to change it. The more so as new technologies cannot always secure the same level of security as provided by earlier, already-proven technologies and solutions [82] (pp. 283–294);
6. Anthropological dilemmas—digital technologies can significantly increase the stability of an energy company, allowing it to be controlled in real-time mode. Therefore, the time needed to adopt important decisions is significantly reduced. At the same time, there is a specific disproportion between the speed, complexity and scope of the changes taking place and human perceptive abilities limited by their natural properties as biological beings [86];
7. New forms of interaction with the service user—digital transformation has significantly changed the culture of communication between the distributor of energy and

its user. This applies, inter alia, to ways of shaping flexible tariffs, and the need for clients to know digital technologies. Increasingly, the user is served without an assistant, which is replaced by chatbots. The latter solution, so far, works only in the performance of standard, non-complex tasks. In many cases, solving a problem or doubt requires talking to a person [90] (pp. 189–194). In addition, very often the client's need to get direct feedback from the assistant is still indispensable.

Proposed answers to the above dilemmas and challenges:

1. New technologies are expected to raise the possibility of forecasting unexpected natural or technological phenomena to a qualitatively new level. Apart from that, more and more demands are placed on the technology of producing electric networks. They must be able to adapt to step changes in voltage in the network, to the situation of excess electricity or its increased consumption [91];
2. The lack of homogeneity results in the need to adopt an open standard of information exchange, which will ensure the cooperation of different energy microsystems (Power Line Communication, Common Information Model). This will facilitate the synchronization between photovoltaic stations and windmills subject to different work rhythms and dependencies on the weather and will mitigate against voltage spikes or energy shortages in the grid [91];
3. One of the world leaders in the energy industry, Siemens AG, and its partners work on digital security issues in close cooperation with Kaspersky Lab (Moscow, Russia). The human factor remains the key factor in maintaining safety. In the manuals for its certified products, the corporation recommends, inter alia, making frequent updates of all hardware and software. An additional instrument for ensuring digital security in this corporation is a team of experts at a global level and a "rapid response" team at the local level [86]. Other providers of energy services and solutions, such as Schneider Electric (Le Creusot, France), are also expanding their field of activity. Until recently, this corporation was only involved in creating a system, which was then used by the personnel of energy companies. Today Schneider Electric has its own staff to control the Cloud Computing infrastructure and develops solutions and services, which are aimed at, for example, helping customers reduce energy costs (Resource Adviser system based on Cloud computing). At Schneider Electric, security issues are dealt with by the Cyber Security International Center. It is a cross-business team that analyzes and audits new solutions (hardware and software) developed by other departments of the company. The same team is also responsible for the development of the Hardening Guide to support hundreds of individual devices (including printers!) forming a coherent system. This manual includes, among others, a checklist of actions that must not be forgotten (e.g., "disconnect http or default port", "change administrator password"). The company also conducts training courses for customers on the operation of their products [85];
4. Today, the profile of engineering teams dealing with the implementation of systems in facilities has changed significantly. In the past, their qualifications were limited to knowledge of Windows OS and products proposed by a specific developer. Today, these specialists must know at least about the administration in Linux, RESTful API and the HTTP and WebSocket protocols by which data is exchanged between individual system components [85];
5. Digital transformation must be carried out carefully and take into account local conditions (power plants, grids, specificity of a market). Implementation of new technologies should take into account the standards existing in a given area. Due to the rapid expansion of the range of production and the type of technologies that must take into account local specifics, Schneider Electric opens local R&D development centres in various countries, as global centres cannot always meet the requirements of local markets [85,87];
6. There is a high probability that the function of the plant operator will be reduced over time to the role of a bio-robot operating in strict accordance with the recommendations

of the AI controlling all processes in the plant. This raises more general questions about the place of humans in the new reality shaped by the latest digital technologies;

7. When encountering new digital technologies in the area of customer service, the end user must be convinced that the changes made have contributed to the increase in the convenience and security of contact with the corporation. The user interface has to become more and more intuitive. When proposing new solutions, the corporation should maintain a proper caution, offering clients only proven solutions [91].

The reigning or consciously created social consciousness largely determines our future. We choose how we want to live, and what values and goals are important to us [92]. There may not be only one right strategy for the future. Therefore, when implementing new digital solutions, one should not be radical. Different approaches in the field of energy, more traditional and modern ones, can coexist [91]. One should choose solutions appropriate for a given place and time, solutions effective in solving specific tasks. It is worth following the path of evolution rather than revolution [84]. A rapid transition from one system to another is associated with instability and an increase in risk.

Digital transformation should solve specific problems and bring about concrete improvements in terms of stability, saving, comfort and security. People and their welfare must remain the overriding concern underlying all these changes [91]. It should also be remembered that digital transformation consists not only in the emergence of new business and engineering practices but above all in the transformation of the very culture of production, distribution and use of energy. Digitalisation changes the very paradigm of thinking about energy [93]. In the course of digital transformation, human resources are shifted from existing processes and practices to others, mainly related to the maintenance of information systems. People still remain the main point of digital transformation.

6. Conclusions

The energy sector is an important sector of the economy, determining the socio-economic development of each country and, globally, having a strong impact on the environment and climate change. This makes energy an area of the global economy where major technological and organisational transformations are taking place, based on a wide range of digital innovations being implemented. In this paper, we have reviewed existing research on drivers, business models and prospective directions of change of energy sector companies in the context of the digitalisation processes taking place in them.

With reference to the first research question, the conducted literature review allowed us to identify drivers influencing the digitalisation of energy industry enterprises, among which we distinguished those characteristics for this sector and those relating to all business entities, being a part of the more general phenomena of Industry 4.0 and Industry 5.0. We found that a number of sector-specific drivers influence the pace, course and effects of these processes. They include different socio-economic conditions, related on the one hand to the increasing consumption of electricity by economies and societies, and—on the other hand—to shrinking conventional energy resources. They also result from the current energy policy in the European Union, which aims at decarbonising the economy, rising energy efficiency and increasing the share of production from renewable energy sources. The digitalisation of energy companies can greatly facilitate adaptation to these requirements, representing a key factor for their rapid and efficient development, fostering the simultaneous achievement of the three priorities: the sustainability, energy security and competitiveness of the energy sector. As another sector-specific driver, we have identified the increasingly distributed nature of electricity production in the energy sector, in which the voice of prosumers, who want to gain greater control over energy management, use and production, is also increasingly heard. This is shifting more and more attention towards small, distributed, local and dynamic activities and businesses that are changing the fundamentals of the energy market. In parallel, energy sector companies are being impacted by other digitalisation drivers, which are also noticeable in other industries, and are therefore of a universal nature. They stem from the ongoing digital transformation of the business sector, which is a part of the more general phenomena of Industry 4.0 and Industry 5.0. Our review shows that digitalisation makes it possible to respond to all these challenges in both the supply and demand sides of the market. For energy suppliers, it offers higher system efficiency, the opportunity to make full use of data and implement new strategies and business models, while for consumers and prosumers, it offers comfort and a reduction in energy consumption costs.

The research review showed that a method to improve the efficiency of energy companies is to implement technological innovations, including those enabling their digital transformation, which changes the essence of their operations and affects all aspects of their activities. At the same time, this means introducing new strategies and business models. With reference to the second research question, we have identified several innovative business models in the energy industry, which are or will be actively implemented in the near future thanks to digitalisation as a response to current trends in the energy market. They include new concepts of doing business in the energy sector based on the idea of peer-to-peer (P2P) electricity trading, virtual power plants (VPPs), flexibility management, local energy markets and the vehicle-to-grid concept. Analysing the described emerging innovations in business models in the energy sector as a result of digitalisation, it can be concluded that the boundary between supply and demand may be blurred in a digitised future. The deployment of smart grids, interconnected and interoperable energy trading and management systems, as well as the exploitation of the potential of artificial intelligence, blockchain and other digital technologies, can completely change the position and roles played by suppliers and consumers. New roles and new actors, such as prosumers or aggregators, are emerging in the transforming energy market, and the range of possibilities for their creation seems to be essentially limitless. As the review of research showed, the new business models being implemented in the energy sector encourage, on the one hand, large generators to transform their operations, including through the possibility to use RES, thus enabling them to adapt to the trends observed in the market, while, on the other hand, they support small prosumers in being active in the energy market, which encourages the active building of a demand-supply balance.

Answering the third research question, what prospective directions of changes will determine the paths of development for the energy sector enterprises in the near future, based on a literature review we identified the main challenges and dilemmas in the energy sector in connection with its digitalisation. We have included here: the risk of destabilisation of the energy market resulting from its decentralisation, the new requirements placed on the competences of those working in the energy sector, the new culture of interaction between energy suppliers and consumers and the digital security of data used in the energy system. Digital transformation should correspond closely to these concerns and offer concrete improvements in terms of stability, savings, convenience and security in the energy sector. In this context, this process is a crucial component of shaping the information society and the implementation of the global plan of sustainable development.

Our research contributes to revealing the potential opportunities, threats and challenges of the digital transformation of the energy sector, and all the results obtained and the conclusions expressed should be treated as a stimulus for further in-depth research, especially on the issue of innovation in the field of new business models resulting from digitalisation, which will provide greater opportunities for implementing sustainable energy transformation and on solutions that will be a response to the above-mentioned risks and dilemmas related to the digitalisation processes in this sector. Regarding the directions for future research, it should be pointed out that there is a constant need to monitor the factors forcing the necessary changes or fostering the transformation of the energy sector, especially in the context of the possibility of using digital technologies to improve existing or implement new, innovative business models that meet the complex needs of various stakeholders of the energy system.

Author Contributions: Conceptualization, B.S-T., S.K., P.K., A.T. and K.Ż.; Formal analysis, B.S.-T., S.K., P.K., A.T. and K.Ż.; Investigation, B.S.-T., S.K., P.K., A.T. and K.Ż.; Methodology, B.S.-T., S.K., P.K., A.T. and K.Ż.; Resources, B.S.-T., S.K., P.K., A.T. and K.Ż.; Writing—original draft, B.S.-T., S.K., P.K., A.T. and K.Ż.; Writing, review & editing, B.S.-T., S.K., P.K., A.T. and K.Ż. All authors have read and agreed to the published version of the manuscript.

Funding: This publication is a component of scientific research carried out at the University of Economics in Cracow as a part of the research of the Potential Program in 2022 no 056/ZZE/2022/POT.

Data Availability Statement: Public databases.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Manterys, A. *Wielość Rzeczywistości w Teoriach Socjologicznych*; Wydawnictwo Naukowe PWN: Warszawa, Poland, 1997.
2. Hołodnik, D.; Perechuda, K. Przedsiębiorstwo nowej generacji. In *Annales Universitstis Mariae Curie-Słodowska, Section H 2—Oeconomia*; Wydawnictwo Uniwersytetu Marii Curie-Skłodowskiej: Lublin, Poland, 2016; pp. 21–27.
3. Bughin, J.; Manyika, J. Leveraging "enterprise 2.0" for competitive advantage. In Proceedings of the IADIS International Conference on WWW/Internet, Vila Real, Portugal, 5–8 October 2007.
4. Trimi, S.; Galanxhi, H. The Impact of Enterprise 2.0 in Organizations. *Serv. Bus.* **2014**, *8*, 405–424. [CrossRef]
5. Williams, S.P.; Hausmann, V.; Hardy, C.A.; Schubert, P. Enterprise 2.0 Research: Meeting the Challenges of Practice. In *BLED 2013 Proceedings*; AISeL: Tokyo, Japan, 2013; p. 33.
6. Bassus, O.; Zaščerinska, J.; Ahrens, A. From Enterprise 2.0 to 3.0: Challenges in Engineering and Business Education. In *Information and Communication Technologies in Engineering and Business*; Bassus, O., Ahrens, A., Lange, C., Eds.; Mensch & Buch: Berlin, Germany, 2011; pp. 79–96.
7. Venselaar, J. (Ed.) *Sustainable Enterprise 3.0 The Strategic Approach out of Economic Self-Interest*; Avans University of Applied Sciences: Breda, The Netherlands, 2014.
8. McAfee, A. *Enterprise 2.0: New Collaborative Tools for Your Organizations Toughest Challenges*; McGraw-Hill Education Ltd.: New York, NY, USA, 2009.
9. Tutaj, J. Digitalisation of Services in the Business Model of a Spa Enterprise Based on the Example of the "Kuracjusz" Program. *Przedsiębiorczość–Edukacja* **2019**, *15*, 171–183.
10. Kania, K. *Technologie informatyczne firmy 2.0*; Wydawnictwo Uniwersytetu Ekonomicznego w Katowicach: Katowice, Poland, 2010.
11. Czakon, W.; Szostak, J.W. *Strategie Przedsiębiorstw w Sieci*; Szostak, J., Ed.; Zeszyty Naukowe Wydziału Zamiejscowego w Chorzowie Wyższej Szkoły Bankowej w Poznaniu: Poznań, Poland, 2017; No. 19; pp. 9–11.
12. Lichtarski, J.M.; Piórkowska, K. Rekin i przywódca stada. Strategie przedsiębiorstw dominujących w sieciach międzyorganizacyjnych. In *Strategie przedsiębiorstw w sieci*; Szostak, J., Ed.; Zeszyty Naukowe Wydziału Zamiejscowego w Chorzowie Wyższej Szkoły Bankowej w Poznaniu: Poznań, Poland, 2017; No. 19; pp. 15–27.
13. Johnston, D.A.; Wade, M.; Mcclean, R. Does e-business matter to SMEs? A comparison of the financial impacts of internet north American SMEs. *J. Small Bus. Manag.* **2007**, *45*, 354–361. [CrossRef]
14. Depaoli, P.; Za, S.; Scornavacca, E. A model for digital development of SMEs: An interaction-based approach. *J. Small Bus. Enterp. Dev.* **2020**, *27*, 1049–1068. [CrossRef]
15. Czech, A. Zarys ewolucji wspólnego rynku energii w Unii Europejskiej. *Stud. Ekon.* **2012**, *123*, 251–262.
16. Carfora, A.; Pansini, R.V.; Scandurra, G. Energy dependence, renewable energy generation and import demand: Are EU countries resilient? *Renew. Energy* **2022**, *195*, 1262–1274.
17. Pindór, T.; Preisner, L. World Coal Sector Restructuring due to Sustainable Development. In Proceedings of the 21st World Mining Congress New Challenges and Visions for Mining, Katowice, Poland, 7–11 September 2008; Kicki, J., Sobczyk, E.J., Eds.; A Balkema Book. CRC Press Taylor & Francis Group: London, UK, 2008; pp. 155–163.
18. Preisner, L. Restrukturyzacja przemysłu naftowego w Polsce w kierunku równoważenia rozwoju. In *Zrównoważony Rozwój Regionów Uprzemysłowionych*; Lorek, E., Ed.; Wydawnictwo Akademii Ekonomicznej w Katowicach: Katowice, Poland, 2009; Volume 2, pp. 127–136.
19. Pindór, T.; Preisner, L. Oszczędność zasobów energii pierwotnej w skali światowej w wyniku zagospodarowania złóż niekonwencjonalnego gazu ziemnego. In *Efektywne Gospodarowanie Zasobami Przyrodniczymi i Energią*; Graczyk, A., Ed.; Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu; Wydawnictwo Uniwersytetu Ekonomicznego we Wrocławiu: Wrocław, Poland, 2013; No. 317; pp. 44–52.
20. Lutz, L.M.; Fischer, L.B.; Newig, J.; Lang, D.J. Driving factors for the regional implementation of renewable energy—A multiple case study on the German energy transition. *Energy Policy* **2017**, *105*, 136–147. [CrossRef]
21. *Słownik wyrazów Obcych*; Wydawnictwo Naukowe PWN: Warszawa, Poland, 1991; p. 898.
22. Parysek, J.J. *Rozwój Społeczno-Gospodarczy Oraz Czynniki i Uwarunkowania Rozwoju*; Studia Komitetu Przestrzennego Zagospodarowania Kraju PAN: Warszawa, Poland, 2018; No. 183; p. 44.

23. Stanienda, J. *Determinanty Rozwoju i Konkurencyjności Przedsiębiorstw w Regionie*; Małopolska Wyższa Szkoła Ekonomiczna w Tarnowie: Tarnów, Poland, 2006; s. 24.
24. *Encyklopedia Powszechna PWN*; Publisher PWN: Warszawa, Poland, 1982; p. 150.
25. Kaleta, A. Zewnętrzne i wewnętrzne warunki rozwoju przedsiębiorstw. In *Przedsiębiorczość i Innowacyjność Małych i Średnich Przedsiębiorstw—Wyzwania Współczesności*; Kaleta, A., Moszkowicz, K., Woźniak, L., Eds.; Prace Naukowe Akademii Ekonomicznej im.; O. Langego we Wrocławiu, Uniwersytet Ekonomiczny we Wrocławiu: Wrocław, Poland, 2004; No. 1030.
26. Chomątowski, S. *Dynamika Rozwoju a Efektywność Systemów Przemysłowych*; Zeszyty Naukowe, Seria Specjalna: Monografia 19; Wydawnictwo Akademii Ekonomicznej w Krakowie: Kraków, Poland, 1993; No. 115; p. 39.
27. Chomątowski, S. Warunki a czynniki rozwoju przedsiębiorstwa. Próba identyfikacji i klasyfikacji. In *Restrukturyzacja w Procesie Przekształceń i Rozwoju Przedsiębiorstw*; Borowiecki, R., Ed.; Akademia Ekonomiczna w Krakowie-TNOiK: Kraków, Poland, 1996; p. 175.
28. Chomątowski, S. Cele, kierunki oraz kryteria analiz i ocen zmian wielkości i struktury działalności gospodarczej przedsiębiorstw. In *Dynamika i Kierunki Zmian Wielkości i Struktury Sektora Przedsiębiorstw w Polsce w Latach 1990–2005*; Chomątowski, S., Ed.; Wydawnictwo Fundacji Uniwersytetu Ekonomicznego w Krakowie: Kraków, Poland, 2009; p. 34.
29. *Scenariusze Rozwojowe dla Polski w Perspektywie Roku 2050*; Raport; Departament Strategii Rozwoju Ministerstwa Inwestycji i Rozwoju: Warszawa, Poland, 2019.
30. *Global Energy. Perspective 2022*; Report; McKinsey and Company: Atlanta, GA, USA, 26 April 2022; p. 6.
31. Barbier, B. *A Global Green New Deal*; Executive Summary Report, prepared for Green Economy Initiative and the Division of Technology Institute of the UN Environment Program; UNEP: Nairobi, Kenya, 2009; p. 4.
32. You, Y.; Yi, L. A Corpus-based empirical study on energy enterprises digital transformation. *Energy Rep.* **2021**, *7*, 198–209. [CrossRef]
33. Park, C.; Cho, S.; Heo, W.G. Study on the future sign detection in areas of academic interest related to the digitalization of the energy industry. *J. Clean. Prod.* **2021**, *313*, 127801. [CrossRef]
34. Kucharska, A. Digitalizacja sektora energetycznego a potencjalne zagrożenia na przykładzie Niemiec. In *Zagrożenia Ładu Społecznego oraz Bezpieczeństwa Narodowego: Wybrane Aspekty*; Gitling, M., Wojaczek, I., Eds.; Instytut Socjologii Państwowej Wyższej Szkoły Wschodnioeuropejskiej: Przemyśl, Poland, 2017.
35. Śledziewska, K.; Włoch, R. *Gospodarka Cyfrowa jak Nowe Technologie Zmieniają Świat*; Wydawnictwo Uniwersytetu Warszawskiego: Warszawa, Poland, 2020; p. 78.
36. Pieriegud, J. Cyfryzacja gospodarki i społeczeństwa—Wymiar globalny, europejski i krajowy. In *Cyfryzacja Gospodarki i Społeczeństwa –Szanse i Wyzwania dla Sektorów*; Gajewski, J., Paprocki, W., Pieriegud, J., Eds.; Instytut Badań nad Gospodarką Rynkową—Gdańska Akademia Bankowa: Gdańsk, Poland, 2016; pp. 11–13.
37. Borowiecki, R.; Siuta-Tokarska, B.; Maroń, J.; Suder, M.; Thier, A.; Żmija, K. Developing Digital Economy and Society in the Light of the Issue of Digital Convergence of the Markets in the European Union Countries. *Energies* **2021**, *14*, 2717. [CrossRef]
38. Avdeeva, E.; Davydova, T.; Belyantseva, O.; Makeeva, T. Factors of Sustainable Development of Energy Technologies in the Formation of Digital Economy. In Proceedings of the E3S Web Conference "Topical Problems of Green Architecture, Civil and Environmental Engineering" (TPACEE 2019), Moscow, Russia, 19–22 November 2019; pp. 19–22.
39. Morishita-Steffen, N.; Alberola, R.; Mougeot, B.; Vignali, E.; Wikström, C.; Montag, U.; Gastaud, E.; Lutz, B.; Hartmann, G.; Pfaffenbichler, F.X.; et al. Smarter together: Progressing smart data platforms in Lyon, Munich, and Vienna. *Energies* **2021**, *14*, 1075. [CrossRef]
40. Borowski, F. Innovative Processes in Managing an Enterprise from the Energy and Food Sector in the Era of Industry 4.0. *Processes* **2021**, *9*, 381. [CrossRef]
41. Kauf, S.; Laskowska-Rutkowska, A. Cyfryzacja w usprawnianiu zarządzania łańcuchem dostaw. In *Cyfryzacja w Zarządzaniu*; Laskowska-Rutkowska, A., Ed.; CeDeWu: Warszawa, Poland, 2020; pp. 56–65.
42. Akberdina, V.; Osmonova, A. Digital transformation of energy sector companies. *E3S Web Conf.* **2021**, *250*, 06001. [CrossRef]
43. Osmundsen, K. Competences for Digital Transformation: Insights from the Norwegian Energy Sector. In Proceedings of the 53rd Hawaii International Conference on System Sciences, HICSS, Wailea, HI, USA, 7 January 2020; pp. 4326–4335.
44. Światowiec-Szczepańska, J.; Stępień, B. Drivers of Digitalization in the Energy Sector—The Managerial Perspective from the Catching Up Economy. *Energies* **2022**, *15*, 1437. [CrossRef]
45. Küfeoğlu, S.; Liu, G.; Anaya, K.; Pollitt, M.G. Digitalisation and New Business Models in Energy Sector. In *Cambridge Working Papers in Economics*; University of Cambridge, Faculty of Economics: Cambridge, UK, 2019; p. 1. Available online: http://www.jstor.org/stable/resrep30431 (accessed on 16 September 2022).
46. Borowski, P.F. Digitization, Digital Twins, Blockchain, and Industry 4.0 as Elements of Management Process in Enterprises in the Energy Sector. *Energies* **2021**, *14*, 1885. [CrossRef]
47. Verma, P.; Savickas, R.; Buettner, S.M.; Strüker, J.; Kjeldsen, O.; Wang, X. Digitalization: Enabling the New Phase of Energy Efficiency. *Group of Experts on Energy Efficiency, GEEE-7*. 2020. NF.3. Available online: https://unece.org/sites/default/files/2020-12/GEEE-7.2020.INF_.3.pdf (accessed on 15 September 2022).
48. Wang, Z.; Yu, X.; Mu, Y.; Jia, H. A distributed Peer-to-Peer energy transaction method for diversified prosumers in Urban Community Microgrid System. *Appl. Energy* **2020**, *260*, 114327. [CrossRef]

49. Schneiders, A.; Fell, M.J.; Nolden, C. Peer-to-peer electricity trading and the sharing economy: Social, markets and regulatory perspectives. *Energy Sources Part B Econ. Plan. Policy* **2022**. [CrossRef]
50. Wilkinson, S.; Hojckova, K.; Eon, C.; Morrison, G.M.; Sandén, B. Is peer-to-peer electricity trading empowering users? Evidence on motivations and roles in a prosumer business model trial in Australia. *Energy Res. Soc. Sci.* **2020**, *66*, 101500. [CrossRef]
51. Zhou, Y.; Wu, J.; Long, C.; Ming, W. State-of-the-Art Analysis and Perspectives for Peer-to Peer Energy Trading. *Engineering* **2020**, *6*, 739–753. [CrossRef]
52. The Future of Digitization in the Energy Sector. (In Polish). *Transformacja*. 2050. Available online: https://transformacja2050.pl/project/cyfryzacja-w-energetyce-analiza/ (accessed on 9 September 2022).
53. Liu, H.; Zhang, Y.; Zheng, S.; Li, Y. Electric Vehicle Power Trading Mechanism Based on Blockchain and Smart Contract in V2G Network. *IEEE Access* **2019**, *7*, 160546–160558. [CrossRef]
54. Mengelkamp, E.; Gärttner, J.; Rock, K.; Kessler, S.; Orsini, L.; Weinhardt, C. Designing microgrid energy markets—A case study: The Brooklyn Microgrid. *Appl. Energy* **2018**, *210*, 870–880. [CrossRef]
55. Shafiekhani, M.; Hashemizadeh, A. Multi-objective scheduling of a virtual power plant considering emissions. In *Scheduling and Operation of Virtual Power Plants*; Zangeneh, A., Moeini-Aghtaie, M., Eds.; Elsevier: Amsterdam, The Netherlands, 2022; pp. 377–397. [CrossRef]
56. Asmus, P. Microgrids, Virtual Power Plants and Our Distributed Energy Future. *Electr. J.* **2010**, *23*, 72–82. [CrossRef]
57. Ropuszyńska-Surma, E.; Węglarza, M. The Virtual Power Plant—A Review Of Business Models, E3S Web of Conferences. *Energy Fuels* **2019**, *108*, 01006. [CrossRef]
58. Baidya, S.; Potdar, V.; Ray, P.P.; Nandi, C. Reviewing the opportunities, challenges, and future directions for the digitalization of energy. *Energy Res. Soc. Sci.* **2021**, *81*, 102243. [CrossRef]
59. Georgakopoulos, D.; Quigg, S. Precision measurement system for the calibration of Phasor Measurement Units. In Proceedings of the Conference on Precision Electromagnetic Measurements (CPEM), Ottawa, AT, Canada, 10–15 July 2016; pp. 1–2. [CrossRef]
60. Olivella-Rosell, P.; Viñals-Canal, G.; Sumper, A.; Villafafila-Robles, R.; Bremdal, B.A.; Ilieva, I.; Ottesen, S.Ø. Day-ahead micro-market design for distributed energy resources. In Proceedings of the IEEE International Energy Conference (ENERGYCON), Leuven, Belgium, 4–8 April 2016; pp. 1–6. [CrossRef]
61. Schreck, S.; Sudhoff, R.; Thiem, S.; Niessen, S. On the Importance of Grid Tariff Designs in Local Energy Markets. *Energies* **2022**, *15*, 6209. [CrossRef]
62. Beattie, S.; Chan, W.-K.; Wei, Z.; Zhu, Z. Simulation Analysis of a Double Auction-Based Local Energy Market in Socio-Economic Context. *Sustainability* **2022**, *14*, 7642. [CrossRef]
63. Klaina, H.; Guembe, I.P.; Lopez-Iturri, P.; Astrain, J.J.; Azpilicueta, L.; Aghzout, O.; Alejos, A.V.; Falcone, F. Aggregator to Electric Vehicle LoRaWAN Based Communication Analysis in Vehicle-to-Grid Systems in Smart Cities. *IEEE Access* **2020**, *8*, 124688–124701. [CrossRef]
64. Cleveland, C.J.; Morris, C. *Dictionary of Energy*; Elsevier: Amsterdam, The Netherlands, 2006; p. 473.
65. Mroczek, B.; Kołodyńska, A. The V2G Process with the Predictive Model. *IEEE Access* **2020**, *8*, 86947–86956. [CrossRef]
66. Brzóska, J.; Krannich, M. Modele biznesu innowacyjnej energetyki. *Stud. Ekon.* **2016**, *280*, 7–20.
67. Kaleta, A.; Radomska, J.; Sołoducho-Pelc, L. The relationship between the approach to strategic management and innovativeness in companies of various sizes. *Argum. Oeconomica* **2018**, *40*, 203–224. [CrossRef]
68. Ates, A.; Garengo, P.; Cocca, P.; Bititci, U. The Development of SME Managerial Practice for Effective Performance Management. *J. Small Bus. Enterp. Dev.* **2013**, *20*, 28–54. [CrossRef]
69. Rokonuzzaman, M. Industrial Strategy in the Advanced Digital Age. *The Financial Express*. 2020. Available online: https://thefinancialexpress.com.bd/public/views/industrial-strategy-in-the-advanced-digital-age-1579013765 (accessed on 7 September 2022).
70. Trzaska, R.; Sulich, A.; Organa, M.; Niemczyk, J.; Jasiński, B. Digitalization Business Strategies in Energy Sector: Solving Problems with Uncertainty under Industry 4.0 Conditions. *Energies* **2021**, *14*, 7997. [CrossRef]
71. Fattouh, B.; Poudineh, R.; West, R. The rise of renewables and energy transition: What adaptation strategy exists for oil companies and oil-exporting countries? *Energy Transit* **2019**, *3*, 45–58. [CrossRef]
72. Hirsch, A.; Parag, Y.; Guerrero, J. Microgrids: A review of technologies, key drivers, and outstanding issues. *Renewable and Sustainable Energy Reviews* **2018**, *90*, 402–411. [CrossRef]
73. Wagner, O.; Götz, T. Presentation of the 5Ds in Energy Policy: A Policy Paper to Show How Germany Can Regain Its Role as a Pioneer in Energy Policy. *Energies* **2021**, *14*, 6799. [CrossRef]
74. Idries, A.; Krogstie, J.; Rajasekharan, J. Challenges in platforming and digitizing decentralized energy services. *Energy Inform* **2022**, *5*, 1–29. [CrossRef]
75. Silvente, J.; Kopanos, G.M.; Pistikopoulos, E.N.; Espuña, A. A rolling horizon optimization framework for the simultaneous energy supply and demand planning in microgrids. *Apply Energy* **2015**, *155*, 485–501. [CrossRef]
76. Alstone, P.; Gershenson, D.; Kammen, D.M. Decentralized energy systems for clean electricity access. *Nat. Clim. Chang.* **2015**, *5*, 305–314. [CrossRef]
77. Adil, A.M.; Ko, Y. Socio-technical evolution of decentralized energy systems: A critical review and implications for urban planning and policy. *Renew. Sustain. Energy Rev.* **2016**, *57*, 1025–1037. [CrossRef]
78. *Distributed Generation in Liberalised Electricity Markets*; International Energy Agency: Paris, France, 2002.

79. Pal, N.S.; Shrivastava, V. A review on distributed generation definitions and DG impacts on distribution system. In Proceedings of the International Conference on Advanced Computing and Communication Technologies, Washington, DC, USA, 6–7 April 2013; pp. 1–7.
80. Khajeh, H.; Laaksonen, H.; Gazafroudi, A.S.; Shafie-khah, M. Towards Flexibility Trading at SO-DSO-Customer Levels: A Review. *Energies* **2020**, *13*, 165. [CrossRef]
81. Kettunen, P.; Mäkitalo, N. Future smart energy software houses. *Futures Res.* **2019**, *7*, 1–25. [CrossRef]
82. Glaa, B. Digitalisation in the Context of Electricity Market Reforms and Liberalisation: Overview of Opportunities and Threats. In *Revisiting Electricity Market Reforms. Lessons for ASEAN and East Asia*; Phoumin, H., Nepal, R., Kimura, F., Uddin, G.S., Taghizadeh-Hesary, F., Eds.; Springer: Singapore, 2022; pp. 283–294.
83. Difference and Similarities: Digitization, Digitalization, and Digital Transformation; GlobalSign Blog. 2022. Available online: https://www.globalsign.com/en-sg/blog/difference-and-similarities-digitization-digitalization-and-digital-transformation (accessed on 20 September 2022).
84. Tiefenbeck, V. Bring behaviour into the digital transformation. *Nat. Energy* **2017**, *2*, 1–3. [CrossRef]
85. Safety Solutions; Schneider Electric: Le Creusot, France. 2022. Available online: www.se.com/us/en/work/solutions/safety (accessed on 5 August 2022).
86. Smart Grids für Energieversorger; Siemens AG: Munich, Germany. 2022. Available online: https://new.siemens.com/de/de/produkte/energie/themen/smart-grid.html (accessed on 10 September 2022).
87. *Revisiting Electricity Market Reforms. Lessons for ASEAN and East Asia*; Phoumin, H.; Nepal, R.; Kimura, F.; Uddin, G.S.; Taghizadeh-Hesary, F. (Eds.) Springer: Singapore, 2022.
88. What went wrong with the Texas power grid? *Houston Chronicle*, 15 February 2021.
89. *GB Power System Disruption*; Interim Report; Energy Emergencies Executive Committee; Department for Business, Energy & Industrial Strategy: Washington, DC, USA, 2019; pp. 4–20.
90. Hilbert, M. Digital technology and social change: The digital transformation of society from a historical perspective. *Dialogues Clin. Neurosci.* **2022**, *22*, 189–194. [CrossRef]
91. IBS Platformix, Service. 2022. Available online: https://platformix.ru/service (accessed on 15 September 2022).
92. Blok, V. The Ontology of Technology Beyond Anthropocentrism and Determinism: The Role of Technologies in the Constitution of the (post) Anthropocene World. *Found. Sci.* **2022**, *9*, 1–19. [CrossRef]
93. Global Energy Transformation: A Roadmap to 2050. *International Renewable Energy Agency*. 2019. Available online: www.h2knowledgecentre.com/content/researchpaper1605 (accessed on 1 October 2022).

energies

MDPI

Article

The Role of Pro-Innovative HR Practices and Psychological Contract in Shaping Employee Commitment and Satisfaction: A Case from the Energy Industry

Katarzyna Gadomska-Lila [1,]* and Anna Rogozińska-Pawełczyk [2]

[1] Department of Organization and Management, University of Szczecin, 71-004 Szczecin, Poland
[2] Faculty of Economics and Sociology, University of Lodz, Gabriela Narutowicza 68, 90-136 Lodz, Poland; anna.rogozinska@uni.lodz.pl
* Correspondence: katarzyna.gadomska-lila@usz.edu.pl

Abstract: Innovation is a very important attribute of energy companies. Its level largely depends on employees' attitudes and behaviours, which are determined on the one hand by individual factors (e.g., psychological contract) and on the other hand by organisational factors (e.g., human resources (HR) practices). The aim of this article is to identify the relationship between pro-innovative HR practices, psychological contract and employee attitudes—commitment and job satisfaction. The research was conducted in a company which is one of the leading Polish electricity suppliers. Data were collected using a proprietary survey questionnaire. The research involved 402 HR professionals responsible for shaping and implementing pro-innovative HR practices in the company. Hypotheses were tested using the partial least squares structural equation modelling technique (PLS-SEM). The results indicate the existence of a positive relationship between pro-innovative HR practices, psychological contract and employee commitment and satisfaction. Furthermore, they indicate that organisations wishing to increase employee commitment and job satisfaction should strengthen and implement existing psychological contracts. One way to do this is to invest in pro-innovative HR practices, such as competence development, knowledge sharing or creativity-based candidate selection, as they have been shown to be good moderators of these relationships. The obtained results may be of particular importance for HR management specialists and managers responsible for shaping desired attitudes and behaviours of employees.

Keywords: energy sector; pro-innovative HR practices; psychological contract; job commitment; job satisfaction

Citation: Gadomska-Lila, K.; Rogozińska-Pawełczyk, A. The Role of Pro-Innovative HR Practices and Psychological Contract in Shaping Employee Commitment and Satisfaction: A Case from the Energy Industry. *Energies* **2022**, *15*, 255. https://doi.org/10.3390/en15010255

Academic Editor: Bernard Ziębicki

Received: 26 November 2021
Accepted: 29 December 2021
Published: 31 December 2021

1. Introduction

Innovation is one of the key determinants of the competitive advantage of companies. The level of organisational innovativeness fundamentally depends on employees' attitudes and behaviours. These attitudes and behaviours are, among others, the result of psychological contracts and the result of implemented management practices, including those identified as pro-innovative HR practices.

The energy sector is one of the most innovative in terms of applied technological solutions, conducted research projects and organisational solutions. The company surveyed is one of the leaders in implementing innovative products and services in many areas of its very broad and diverse activities. Its brand belongs to one of the largest companies in Europe, which makes it universally recognisable. Its well-established position on the Polish market, supported by the trust of institutional and individual clients, as well as its prestige make it attractive for research.

In terms of its wide range of activities, since 2014, it has also held an active concession for trading electricity in Poland. The company has been recognised as a leader in the implementation of new solutions and the use of tools not only in energy production and distribution or digital solutions, but also in management practices, especially pro-innovative HR practices. The scale of operations and related needs justified the creation of a separate HR structure in the company under study, with several hundred employees specialising in this area. The aim of the article is to identify the relationship between pro-innovative HR management practices, psychological contract, and employee commitment and satisfaction. The study undertaken analyses the impact of the application of pro-innovative HR practices related to the deliberate implementation of modern technologies within an energy distribution company in Poland on employees' psychological contracts, sense of job satisfaction and employee commitment. The surveyed company is the largest alternative energy retailer in Poland. It is a leader in creating and implementing pioneering solutions in providing access to stable, sustainable and modern energy. In order to ensure the most substantive assessment, the study selected HR department employees, as the most competent to assess the usefulness of specific tools and solutions.

The subject of the research concerns management problems related to shaping certain attitudes and behaviours of employees, which are relevant to the energy sector. We considered this topic to be important because the innovativeness of organisations in this sector largely depends on the attitudes and behaviours of their employees, and these can be successfully shaped and developed using appropriate HR practices. The research subject, which was a leading energy company, is an excellent example of this.

The current study contributes to the extant literature and practice in several ways. First, this article can contribute to a better understanding of the relationship between pro-innovative human resource management practices, the psychological contract, and employee commitment and satisfaction. This will enable the formation of desirable employee attitudes and the selection of effective tools, especially from the group of pro-innovative HR practices. This topic is important, given the impact of attitudes on employee behaviour, including innovative behaviour, and at the same time the unpromising picture of the labour market and employment problems faced by companies in the energy sector. Second, the study has demonstrated the positive impact of the psychological contract on commitment, and confirmed the relationship between commitment and job satisfaction. Pro-innovative HR practices proved to be a good moderator of this relationship—their introduction strengthens the positive relation between the psychological contract and job satisfaction and commitment. Finally, in the utilitarian dimension, the results of the research may be useful to direct the activities of companies in the energy sector consisting in the search for effective ways of shaping employees' attitudes—commitment and job satisfaction, consequently favouring the development of an effective human resources management policy.

The article consists of five parts. After the introduction, the theoretical framework is presented along with the characteristics of the main variables and relations between them, as a basis for deriving research hypotheses. The following sections describe the research methodology and the research results. Finally, in the last section, a discussion and conclusions are formulated along with practical and theoretical implications as well as limitations of the study and further possible research directions.

2. Theoretical Framework

2.1. Challenges for the Energy Sector in Poland—The Context of Research

The energy sector is one of the sectors of key importance for the economy of any country. No economy can develop without predictable and reliable energy production, distribution and supply. However, the strategic importance of energy companies, resulting from the need to ensure uninterrupted energy supply, is confronted with the impact of their activities on a wide range of stakeholders and on the environment. Therefore, the issue of sustainable development is becoming a priority, and the directives announced by the UN under the name of "Sustainable Development Goals" are becoming a kind of guide, also for companies in this sector [1]. It is difficult to overestimate how impactful the energy sector is and its significance for sustainable development in social, environmental, market and consumer issues. In Poland, issues related to the energy sector, such as ensuring energy security, innovativeness of this sector, intelligent energy management, transformation of the mining sector or diversification of supplies, remain a particular area of interest both for state authorities and managers of companies. Data from the Responsible Business Forum [2] show that there are many energy companies that take a responsible and strategic approach to the challenges of sustainable development—they undertake socially responsible initiatives, care for dialogue and transparency of activities, report non-financial data adhering to the best standards, etc. However, there are still many dimensions in which more activity would be desirable, including environmental, market and consumer ones, such as sustainable production and consumption, energy efficiency or renewable energy sources. It is necessary to invest in energy infrastructure and the creation of clean energy technologies, including renewable energy and cleaner fossil fuel technologies, as well as the improvement of technologies for the provision of modern and sustainable energy services. This emphasises the need to implement innovative solutions, drawing special attention to the human resources of companies in this sector. The challenges they are facing confirm that they have to recruit the best specialists and make sure that such specialists are willing to stay with the organisation as long as possible and that they are committed to achieving its goals. At the same time, energy companies are reporting an increasing demand for staff. Construction of new and expansion of existing power units, modernisation of the network, growing sales of energy, etc. generate the need for new specialised employees. In addition, the current situation on the Polish labour market, referred to as the employee market, means that many companies also have problems with retention and must strive to ensure that employees, especially key ones, remain in the organisation. This justifies directing attention to employee attitudes, especially commitment and job satisfaction. An important role is played here by psychological contracts concluded with employees, as well as the activity of HR department employees, who are responsible for shaping and implementing management practices that favour the development of specific attitudes and behaviours of employees. The specificity of the sector, especially the need to create and develop newer and smarter solutions and to implement the latest technologies, induces the search for HR practices which will positively influence employee involvement and satisfaction, as well as being conducive to innovation. This makes it possible, in a way, to address two key objectives from the Development Agenda—Goal 7 on ensuring access to affordable, reliable, sustainable and modern energy, and Goal 8 on promoting stable, sustainable and inclusive economic growth, full and productive employment and decent work for all people.

2.2. Engagement and Job Satisfaction Versus Pro-Innovative HR Practices and Psychological Contract—Hypothesis Development

Employees' attitudes are a frequent subject of research due to the repeatedly empirically confirmed strong relationship with behaviour and, consequently, with the quality and efficiency of job performance [3,4]. Findings of Harrison, Newman, and Roth [5] suggest that if employees display positive attitudes, they perform better professionally. The consequences of positive attitudes relating to the work environment are specific behaviours (e.g., innovative, proactive, citizenship) as well as job performance. Thanks to the analysis of attitudes, it is also possible to assess the effectiveness of investments in employees. Among the group of attitudes that are particularly effective are job satisfaction and commitment to work. Both attitudes refer to the appraisal and emotional response to the situation in the workplace [6,7], where satisfaction is a more emotional state of well-being resulting from the fulfilment of an employee's needs, and commitment refers to the investment of cognitive, emotional and physical energy in the performance of work activities [8].

Job satisfaction is the most commonly analysed employee attitude in research [9]. It is defined as a general attitude towards work [10] or as an employee's feelings about their job [11]. Robbins and Judge [12] add that this positive feeling about a job stems from an evaluation of its characteristics. As a multidimensional concept, satisfaction includes several aspects of the job. Among these aspects, most researchers point to: job characteristics, relationship with co-workers, relationship with supervisors, recognition and benefits, promotion opportunities and fairness, working conditions, satisfaction with the company and management, communication [13,14]. Satisfaction is the extent to which an employee perceives job needs as fulfilled [15]. Research by Beal and co-authors [16] has shown that job satisfaction can enhance employees' concentration and attention, and ultimately lead to better job performance. On the other hand, Zahoor, Zia, and Rizwan [17] proved the effect of satisfaction on loyalty. It turns out that employees who feel job satisfaction manifest a significantly lower tendency to leave their jobs [18], while a decrease in the level of satisfaction results in an increase in the desire to leave the organization [19].

Work commitment can be defined as an attitude towards an organisation of identification with its organisational goals, willingness to exert effort on its behalf and a strong desire to maintain membership in the organisation [20]. It provides a measure of the strength of the employee's psychological identification with the job. The stronger the commitment, the more important work is to the person and the more difficult it is to separate self-esteem from the work itself [21]. It is generally accepted that people who are strongly committed to work put more effort into it and perform better. Lv and Xu's [22] research demonstrates that work engagement is positively correlated with job performance at both the firm and individual employee levels. Research confirms strong positive relationships between engagement and a variety of positive outcomes in organisations [23,24]. As work engagement increases, the level of work task completion and job support increases [25]. An engaged employee is less likely to be absent and at the same time less likely to leave the organisation [26]. Engagement influences performance, which in turn influences the taking of new, creative initiatives and the willingness to make changes [27]. In addition, employees who have high levels of engagement are more likely to exhibit innovative behaviour at work [28]. The positive emotions that accompany engagement not only motivate employees to take initiative and try different things [6], but also encourage them to collect feedback on their performance [23].

As a result of low work engagement and individuals' low sense of job satisfaction, low levels of work task completion and work support, as well as citizenship and adaptive behaviour can be predicted [8]. Due to the significant impact of commitment and satisfaction on employee behaviour, it is necessary to search for factors that will positively influence these attitudes. Both individual and organisational variables seem to be important. Literature studies confirm that an important individual factor is the psychological contract, which influences employee attitudes and behaviours as well as organisational performance [29]. The psychological contract is an implicit agreement between the individual and the organization that defines what each person expects to offer and receive. It is a set of people's beliefs about the contract that defines the terms of exchange and the resulting benefits for both employer and employee [30]. It develops from the employee's belief in the mutual obligations between him or her and the employer, becoming the basis of the employment relationship [30,31], directing what the organisation expects of him or her and how it will reciprocate for the effort and actions the employee has made on its behalf [32]. This relates to various aspects of the employee relationship within the organisation [33] and the consequences of accepting and fulfilling mutual obligations to achieve the organisation's goals [34]. The psychological contract complements the formal arrangements, so to speak, and indicates expectations that may relate to economic, organisational or psychological issues. It can help employers understand and predict employee behaviour, induce employees to become more committed, and cause employees to pursue company goals to a greater extent [35]. The implementation of psychological contracts is associated with attitudes such as job satisfaction [36], organisational commitment [37] or innovative behaviour [38]. At the same time, an organisation's failure to fulfil its contractual provisions results in negative attitudes and behaviours, such as intentions to leave [39] or failure to exhibit citizenship behaviours [40]. At the organisational level, the variable that significantly influences the formation of employees' attitudes, as well as skills and behaviours, are HR practices [41,42]. They have a synergistic effect that influences employees' attitudes towards work [43]. In particular, they affect job satisfaction and commitment [7,44]. Research by Okabe [45] confirms that HR practices can increase job satisfaction, facilitate knowledge sharing among employees, and contribute to the perception of a more welcoming workplace. This in turn can contribute to more innovative behaviour [46]. Effective HR practices make competent and innovative employees contribute to the achievement of organisational goals [47]. Research also indicates that HR practices influence perceptions of psychological contract [35,48,49]. It is one of the strongest influences on the psychological contract, factors [47]. HR practices and the employment relationship play a very important role in forming and shaping contracts [50]. The organisation and its agents [51] communicate promises and expectations to employees in both overt and covert ways. Overt ways usually include formal contracts and all kinds of written communications and direct interactions, while covert forms of communication are more complex and subtle. An employee can learn about mutual commitments and promises by observing the behaviour and reactions of others in the organisation. Recent research by [52] indicates that the formation of a psychological contract in an organisation is influenced by such perceived commitments as job retention, rapid promotion, satisfactory pay, training and career development. These commitments provide the organization with the opportunity for employees to become more involved in organizational activities and goal achievement.

At the same time, a certain group of HR practices is seen as particularly supportive of organisational innovation [53]. In the managerial dimension, innovation is the ability to recognise and respond not only to current, but also future needs and challenges [54,55]. Research by Oladapo and Onyeaso [56], for example, confirms the link between high performance work practices and organisational innovation. This group of practices is referred to as pro-innovation practices. These include, for example, an emphasis on recruiting staff who are creative and open to change, an emphasis on training and development in the context of innovation, or an emphasis on motivating employees to undertake innovative ventures [57]. Pouwels and Koster [58] also add that higher performance in product and service innovation, market and process innovation is achieved by organisations using training and performance-related pay. Furthermore, research by Cheng and Huand [59] indicates that organisations that invest in strategic HRM are better able to manage their internal knowledge. This in turn has a positive impact on the extent to which these organisations are able to innovate. Developing employees' skills and offering ways to optimise their work (through learning, employability, etc.) are mechanisms through which HRM can contribute to organisational innovation [60].

Various factors, both at the level of the individual (psychological contract) and at the level of the organisation (pro-innovative HR practices) influence employee attitudes, especially satisfaction and commitment, and translate into constructive behaviour in the work environment.

Given the considerations presented, we conclude that knowledge of the relationship between pro-innovative HR practices, psychological contract, job satisfaction and commitment is fundamental in the effort to shape desirable employee attitudes and behaviours. Based on the findings, we pose the following hypotheses:

Hypothesis 1 (H1). *Psychological contract has positive impact on employees' job satisfaction.*

Hypothesis 2 (H2). *Psychological contract has positive impact on employee commitment.*

Hypothesis 3 (H3). *Employee commitment has positive impact on employees' job satisfaction.*

Hypothesis 4 (H4). *Implementing pro-innovative HR practices strengthens the positive relation between psychological contract and employees' job satisfaction.*

Hypothesis 5 (H5). *Implementing pro-innovative HR practices strengthens the positive relation between psychological contract and employee commitment.*

Hypothesis 6 (H6). *Implementing pro-innovative HR practices strengthens the positive relation between employee commitment and employees' job satisfaction.*

A research model was created to show the relationship between the tested features. This is illustrated in Figure 1.

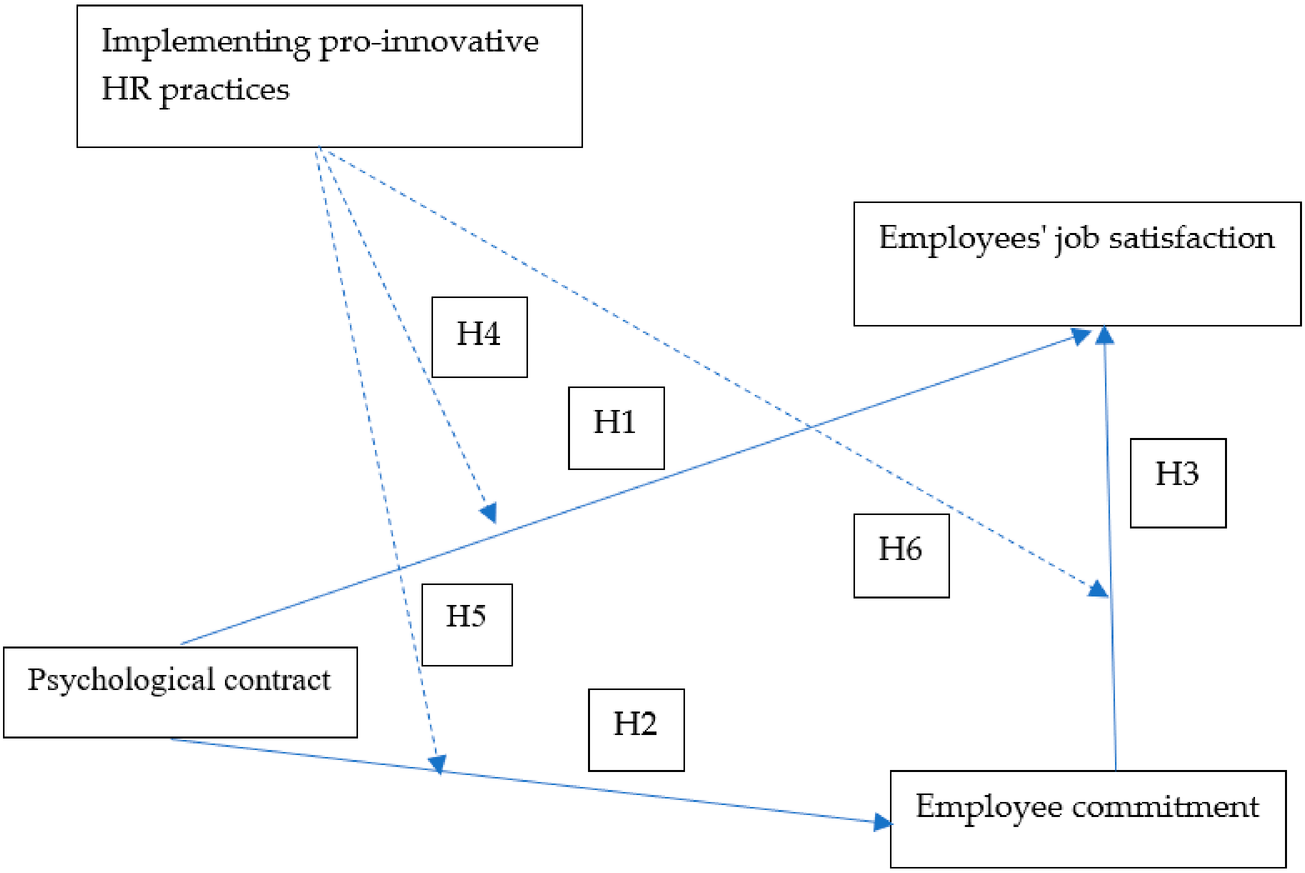


Figure 1. Hypothetical research model. Source: created by the authors.

3. Materials and Methods

3.1. Research Entity

The surveyed entity belongs to a group that is a leader on the Polish fixed telephony, Internet and data transmission market, which, as an innovative provider of ICT and telecommunications services, has the largest, most technologically advanced infrastructure in the country. For seven years, it has also been selling energy under its own brand. Currently, it is the largest alternative energy seller in Poland, with a customer base of over 120,000. Over 97% of households are within the reach of its offer. The company creates and implements pioneering solutions in the scope of providing access to stable, balanced and modern energy. It vigilantly observes the environment and catches all market signals and business opportunities. Based on its strengths, which are the complexity of solutions and knowledge of customer needs, it constantly creates new solutions and enriches its offer. It focuses on innovation. It carries out investments and pro-environmental projects. Currently, it is investing in obtaining electricity from environmentally neutral sources (two wind farms launched for the company), which is part of a broader, ambitious plan—to achieve climate neutrality by 2040. The company's offer also includes Smart Energy solutions, comprising efficient, modern photovoltaic installations producing green energy from solar radiation and a comprehensive monitoring and management system, unique in the market, and as indicated among others by the research of Grębosz-Krawczyk and colleagues [61] on consumers' purchase intentions towards the installation of photovoltaic panels, this is a future-oriented development. The researched company is a leader in introducing innovative solutions in various areas of activity, as well as in the area of human resources management. It encourages its employees to search for and create technological, product and organisational solutions, favourable to energy efficiency, reduction of negative impact on the environment or reduction of resources consumption. It appreciates the importance of human resources. It pursues business objectives with respect for the subjectivity of employees, uses digital solutions, and creates a culture of cooperation in which all employees feel respected and are able to freely pursue their professional objectives.

With the company being recognised as implementing innovative solutions in various areas of activity, including management, the legitimacy of implementing pro-innovative HR practices was analysed in the context of influencing employees' psychological contracts and their attitudes—commitment and satisfaction. In order to ensure the most substantive assessment, HR employees comprising over 400 people were selected for the study.

The choice of HR employees was dictated by the fact that they are best qualified to assess, through their experience, the usefulness of new tools as well as personnel or management solutions. Therefore, the usefulness of these solutions was assessed by all HR department employees, who have the broadest competence in this area and therefore their answers, based on their professional experience, are the most reliable. The research has shown that there is a very large specialised group within this innovative structure, which through its involvement in the research has also in a way confirmed that it was selected accurately.

3.2. Testing Procedure

To achieve the objective of this research and to verify the hypotheses, the survey was conducted in December 2019. The sampling frame consisted of 402 respondents who represented 100% of the HR department employees of the surveyed company. The personnel of the selected organization was surveyed using the "Employee satisfaction survey" method, which was developed by the Partner in the "AnStat" Business Strategies as per the organization's Strategy of Development for the years 2015–2020. We used a self-administered questionnaire consistent with the needs of the contracting authority and purposive sampling [62].

In the first stage, a pilot test was conducted with ten selected HR department staff. During this research process, respondents checked the content and relevance of each item to ensure every question was adequate and understood. Based on the feedback from the pre-test, minor modifications were made to the questionnaire.

In the second stage, a sample of 402 employees was purposively selected for the study and represented 100% of the HR department employees of the surveyed organisation. The quantitative survey followed a standardised procedure [63], through statements aggregated into a diagnostic tool which used the CATI computer-assisted telephone interview technique. The data collected from each interview were analysed for the questionnaire path that was scripted and also for the consistency of the tool. The average duration of the survey (median) was 19 min with an employee.

Table 1 details the structure of the study sample, which presents: gender, age, level of education, total work experience and length of work experience in the current com-pany, as well as the type of HR position in the professional hierarchy.

The results show that the group working in the HR department is relatively feminised, as almost 65% are women. The large portion of participants employed in the HR department are between 30 and 50 years old. The smallest groups are surveyed employees under 30 years old (10.2%) and 55 and over (5%). The majority of participants (82.3%) are highly educated, having a university degree or above. The company has a preference for recruiting employees to the HR department already with significant work experience, as more than half of the participants have more than 10 years of work experience and a quarter of the surveyed group has worked for up to 10 years in total. In addition, employees working in HR department are characterised by long seniority—66.6% have been working in the surveyed company for 6 years and more. The distribution of positions in the professional hierarchy is standard, with the majority of survey participants employed as HR assistants and senior HR assistants (74.8%) and a minority of managers and executives (5.2%).

Table 1. Demographic description of respondents.

Demographic	Descriptors	General	
		n	%
Gender	Male	141	35.1
	Female	261	64.9
Age	<30	41	10.2
	<30–39>	160	39.8
	<40–49>	111	27.6
	<50–54>	70	17.4
	55+	20	5.0
Education	Secondary	71	17.7
	Postgraduate degree (Masters)	287	71.4
	Doctorate PhD	44	10.9
Total Work Experience	Less than year	2	0.5
	1–5 years	53	13.2
	6–10 years	100	24.8
	Over 10 years	247	61.5
Work Experience in existing organization	Less than year	51	12.7
	1–5 years	83	20.7
	6–10 years	144	35.8
	Over 10 years	124	30.8
HR position in the professional hierarchy	HR Director	21	5.2
	HR Manager	80	20.0
	Senior assistants and HR assistants	301	74.8
Total		402	100.0

Source: created by the authors.

3.3. Measures, Validation and Reliability Analysis

Fundamental in the research process was the design of measurement instruments to collect data on the main constructs within the proposed hypotheses. The quantitative study, which used the CATI computer-assisted telephone interview technique to collect empirical material, involved a battery of tests aggregated to a single questionnaire.

The measurement of the study variables was carried out using a set of items derived from adaptations of existing research tools, which were selected on the basis of a literature review. Some tools required cultural adaptation prior to the research. For this purpose, one of the procedures of tool adaptation [64] was used; translation and post-translation from the Polish version of the text to the original (English language) version, in order to faithfully translate the methods used. The translated questionnaires were evaluated by competent judges, who were three independent experts in the fields of English philology, HRM and statistical methods. Attention was also taken to the criterion of equivalence of the questionnaires in the form of: facial, psychometric, functional equivalence and reconstruction validity.

The questionnaire consisted of 35 items taken from the literature measuring basic constructs, such as implementing pro-innovative HR practices, psychological contract, employees' job satisfaction, employee commitment, and the demographic characteristics of respondents (indicated in Table 1), which played the role of control variables. A list of the key constructs used with associated items is presented in Appendix A.

3.4. Implementing Pro-Innovative HR Practices (IPHRP)

Since the impact of HR practices is not immediate and not always in line with employers' expectations, its effect can manifest in the meanings that employees attribute to these practices. The IPHRP construct intended for opinion by employees measured the implementation of pro-innovative HRM practices implemented in the company. It was divided into 4 subscales: (IPHRP I) Personnel pro-innovative activities in the area of employee recruitment (2 items); (IPHRP II) Personnel pro-innovative activities in the area of professional development (3 items); (IPHRP III) Personnel pro-innovative activities in the area of motivation and remuneration (3 items), and (IPHRP IV) Personnel pro-innovative activities in the area of maintaining positive employee relations (4 items). In developing the items within each subscale, we followed the indications by Kinnie and collaborators [65] and Wang and collaborators [66]. As part of the measurement of IPHRP, employees were asked for their opinion on how satisfied they were with the implementation of pro-innovative company's HR practices. All research measures were carried out by a seven-point Likert scale (where 1 = "not at all" and 7 = "to a very high degree") for each item.

3.5. Psychological Contract (PC)

The next section of the questionnaire examining the PC was measured by a single variable: the perceived degree to which the psychological contract was fulfilled. The study measured the extent to which obligations under the PC were fulfilled by the employee and the employer. Items to measure the PC were adapted from the study by Rousseau and Tijoriwala [67] and Guest and Conway [68]. To measure the fulfilment of the employer's and employees' obligations two subscales were used, each containing 9 and 8 items, respectively, such as "To what extent do you fulfil the promises and obligations you made to your employer?" and "How would you rate the fulfilment of promises and obligations by your employer?" All items were assessed by respondents on a seven-point Likert scale, where 1 was "not filled at all" and 7 "completely filled".

3.6. Employees' Job Satisfaction (EJS)

EJS was measured using three items diagnosing general job satisfaction, attitude towards the job and interest in the job. This construct was diagnosed using modified statements taken from the Job Satisfaction Scale by Bettencourt, Gwinner and Meuter [69].

3.7. Employee Commitment (EC)

EC is conceptualised here as the extent to which the employee personally identifies with his or her work and is intra-orientated and motivated towards work. Employee engagement was assessed using three-item scales which were adapted from the studies by MOW [70] and Saks [71].

For the questions in the tool, regarding EJS and EC, respondents were asked to rate the extent to which they agreed or disagreed with the statements on a seven-point Likert scale from 1—"strongly disagree" to 7—"strongly agree".

3.8. Data Analysis

The purpose of this paper is to examine how the introduction of pro-innovation practices into an organisation strengthens the role of psychological contracts between the organisation and its employees and influences employees' attitudes at work—commitment and job satisfaction. This objective was achieved through the following research steps:

Stage 1 consisted of desk research on the current situation of the energy sector in Poland and an introduction to the concepts of pro-innovative HR practices, psychological contract, commitment and job satisfaction (chapter: Theoretical Framework).

Stage two focused on the development of 6 research hypotheses (subsection: Engagement and job satisfaction versus pro-innovative HR practices and psychological contract—hypothesis development).

In stage 3, the research methodology was developed, the survey questionnaire was constructed and validated, the research sample for the study was planned and the pilot study and proper research were conducted (chapter: Materials and Methods).

Step 4 involved the processing of the statistical data obtained from the quantitative CAWI survey (subsection: Data analysis; chapter: Results)

In step 5 we analysed the results of the survey, synthesised and discussed the results of the survey at the organisational level while presenting the research limitations. (Chapter: Discussion).

Quantitative social survey methodology was used in the data compilation. Descriptive statistics such as frequencies, means and standard deviations were used to describe the distributions of respondents in terms of sociodemographic characteristics. The main statistical techniques used for data analysis were EFA, CFA and SEM.

The research process was conducted with exploratory factor analysis (EFA) to possible reduce items and define patterns of constructs in the data set [72,73]. EFA was used to eliminate measurement elements that had less than 0.30 factor loading or had high cross loading over two or more factors [72].Then, Cronbach's Coefficient Alpha was used to control the reliability of internal consistency items [73]. Exploratory factor analysis (EFA) was conducted on the results of the pilot study.

The matching factors were then used in the next step. We used confirmatory factor analysis (CFA) to develop a measurement model and to verify that each of the variables proposed in the research model is valid for the baseline constructs. This research employed confirmatory factor analysis (CFA) with maximum likelihood estimation [74] to test the significance of items' factor loadings to ensure that the items were not loading onto other constructs and to assess the reliability and validity of the multi-item scales. Discriminant validity was assessed in CFA because factor loadings in each construct can be represented by specific scores. CR and AVE also used for assessment in CFA to represent the quality of the constructs. Tables 2 and 3 set out our empirical results in detail.

Table 2. Constructs, measures and factor loadings.

Variable	Subscales	Items	Loading	t-Value	AVE	CR
IPHRP (α = 0.810)	IPHRP I (α = 0.767)		0.701	9.37		
		IPHRP I_1	0.776	8.63		
		IPHRP I_2	0.791	8.29		
	IPHRP II (α = 0.699)		0.735	9.77		
		IPHRP II_1	0.701	5.96		
		IPHRP II_2	0.698	6.71		
		IPHRP II_3	0.732	7.95	0.565	0.876
	IPHRP III (α = 0.711)		0.797	8.91		
		IPHRP III_1	0.824	8.49		
		IPHRP III_2	0.709	6.83		
		IPHRP III_3	0.723	5.47		
	IPHRP IV (α = 0.805)		0.782	10.01		
		IPHRP IV_1	0.689	9.01		
		IPHRP IV_2	0.721	8.34		
		IPHRP IV_3	0.883	6.81		
		IPHRP IV_4	0.718	7.83		

Table 2. *Cont.*

Variable	Subscales	Items	Loading	t-Value	AVE	CR
PC (α = 0.698)	PC I (α = 0.804)		0.731	5.44		
		PC I_1	0.864	9.21		
		PC I_2	0.732	9.16		
		PC I_3	0.719	8.19		
		PC I_4	0.721	9.24		
		PC I_5	0.765	9.59		
		PC I_6	0.722	7.01		
		PC I_7	0.758	6.54		
		PC I_8	0.705	9.04		
		PC I_9	0.744	8.72	0.516	0.821
	PC II (α = 0.798)		0.764	8.53		
		PC II_1	0.795	9.18		
		PC II_2	0.899	7.31		
		PC II_3	0.800	5.24		
		PC II_4	0.857	6.33		
		PC II_5	0.699	7.04		
		PC II_6	0.789	9.98		
		PC II_7	0.797	7.74		
		PC II_8	0.735	7.56		
EJS (α = 0.899)		EJS 1	0.856	8.83		
		EJS 2	0.832	9.21	0.667	0.921
		EJS 1	0.879	8.67		
EC (α = 0.827)		EC 1	0.899	5.88		
		EC2	0.845	6.79	0.715	0.899
		EC 3	0.866	7.16		

Source: created by the authors.

Table 3. Convergent validity of the measurement model.

Variable	AVE	CR	IPHRP	PC	EJS	EC
IPHRP	0.565	0.876	0.765			
PC	0.516	0.821	0.760	0.802		
EJS	0.667	0.921	0.744	0.731	0.872	
EC	0.715	0.899	0.717	0.840	0.705	0.825

Source: created by the authors.

All factor loadings were higher than 0.7 and all t-tests of the variables were significant at the 0.001 level with t-values greater than 2, suggesting adequate level of reliability. The reliability of the scales was conducted by calculating composite reliability (CR) and Cronbach's α. Cronbach's alpha values for all scales exceeded 0.7 and exceeded the recommended threshold level [73]. Composite reliability (CR) of all constructs exceeded the threshold value of 0.7, suggesting internal consistency and reliability [75]. The average variance extracted (AVE) values were higher than 0.50. In addition, all the square roots of AVE are also greater than inter-construct correlations. Thus, the convergent validity of the scales was confirmed [75].

Table 3 suggests good validity of the measurement model. This is also confirmed by the results of the chi-square test, where $p < 0.001$ was obtained, Further measures confirm good model fit—$\chi 2/\mathrm{df} < 5$ [76], RMSEA is less than 0.8 [77], and SRMR is less than 0.08 [76], CFI > 0.9 [78], GFI, AGFI, and gamma exceed 0.95 [76], and Bollen's delta is 0.9, and the parsimonious James-Mulaika-Brett index (PGFI) is greater than 0.7. Importantly, for each of the variables, the parameters (factor loadings and measurement error variance) are statistically significant (by item *t*-test, $p < 0.0001$). The correlation between the variables is also significant ($p < 0.0001$).

Summing up, the CFA supported our measurement model and showed that implementing pro-innovative HR practices, psychological contract, employees' job satisfaction and employee commitment are four distinct constructs.

In a final step, partial least squares structural equation modelling (PLS-SEM) was used to determine the assumed relationships between all constructs. In SEM, the direct and indirect effects of endogenous variables provide the overall relationship between all constructs [74]. In addition, discriminant and convergent significance were represented in SEM, indicating the overall validity of the overall constructs. The SEM procedure including data analysis is further discussed in the next section.

The database and statistical tests were conducted using IBM SPSS PS Clementinei IBM SPSS PS Imago computer software. The Statistica statistical package was used for the analyses, which enabled the data to be entered in numerical form and then carried out statistical analyses, facilitating and accelerating the process of compiling the research results.

4. Results

The theoretical framework of our study became the impact of introducing pro-innovative HR techniques on the relationship between psychological contract, employee commitment and employee's job satisfaction. We assumed that implementing pro-innovative HR practices would have a positive impact on these relationships. In order to test the proposed research hypotheses and to empirically verify the hypothesized research model, we performed partial least squares structural equation modelling. PLS-SEM method is frequently selected to test and develop a theory [79], as well as used in business management or management information systems. Ringle, Sarstedt and Straub [80] argue that the most commonly mentioned reasons for adopting PLS-SEM are associated with non-normal data, small sample sizes and the use of formally measured latent variables. In our study, measures and indicators were developed for the following research constructs: psychological contract, job commitment and employees' job satisfaction.

The size of the research sample (402) that we have selected for the study is also comparatively limited, as the entire Company employs 14,587 people. The study sample thus represents only 2.75% of the total workforce. Therefore, we conclude that PLS-SEM is a better and an appropriate method than other tests to examine the research hypotheses of this study. Table 4 shows that the four hypotheses we developed are supported based on the evaluation of the PLS-SEM model.

Hypothesis H1 must be rejected because psychological contracts have no significant impact on employee's job satisfaction (H1: $\beta = 0.215$; $t = 1.461$, ns). The results obtained are contrary to the research of Khorev and Wechtler [81], who support the idea that positive fulfilment of employers' promises is related to job satisfaction behaviours. Our result suggests a full mediation of employee commitment on the relationship between psychological contract and employee's job satisfaction.

As expected, psychological contract has significant positive impact on employee commitment (H2: $\beta = 0.5040$; $t = 3.049$, $p < 0.01$), which suggests that employees with a sense of fulfilled psychological contract are more committed in their work. Our results confirm that employee commitment has a positive significant impact on employee job satisfaction (H3: $\beta = 0.646$; $t = 3.647$, $p < 0.05$).

Table 4. Hypotheses tests results.

Path Analysis	β-Unstandardized Path Coefficient	t-Value	Significant Level	Results
PC—->EJS	0.215	1.461	ns	H1 is not confirmed
PC—->EC	0.504	3.049	***	H2 is confirmed
EC—->EJS	0.646	3.647	**	H3 is confirmed
IPHRP*PC—->EJS	0.758	5.040	**	H4 is confirmed
IPHRP*PC—->EC	0.471	3.655	**	H5 is confirmed
IPHRP*EC—->EJS	0.189	0.467	ns	H6 is not confirmed

Note. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; ns (not significant). Source: created by the authors.

When testing the moderating effect of implementing pro-innovative HR practices on the relationship among psychological contract, employee commitment and employees' job satisfaction, our study indicates the confirmation of H 4–5. It is found that implementing pro-innovative HR practices strengthens the positive relationship between psychological contract and employee job satisfaction (H4: β = 0.758; t = 5.040, $p < 0.05$). Similarly, implementing pro-innovative HR practices enhances the positive relationship between psychological contract and employee commitment (H5: β = 0.471; t = 3.655, $p < 0.05$).

Our study finds that the implementation of pro-innovative HR practices has no significant impact on the relationship between employee commitment and employees' job satisfaction (H6: β = 0.189; t = 0.467, ns).

5. Discussion

The aim of this study was to investigate the relationship between employees' perceptions of pro-innovative HR practices, psychological contract and their level of job commitment and job satisfaction. The results generally supported the hypothesis that such relationships exist.

Evidence from existing literature shows that employee commitment is crucial for organizational welfare [15,82]. The results of our study show that employee commitment is positively influenced by psychological contracts and employee job satisfaction.

In particular, we found that the psychological contract has a significant positive impact on employee commitment. This finding reinforces well-established knowledge about psychological contracts in the literature. According to Chambel and Oliveira-Cruz, psychological contract fulfilment has a positive impact on employee commitment [83]. The results of Lv and Xu [22] research analysis confirmed that psychological contract breach has a strong negative impact on employee commitment.

Employees who implement psychological contracts know what conditions and level of support they can expect from their employers. In the short–term relationships, they know that their efforts are rewarded in the form of financial compensation without any further obligations or demands [84]. As long as the amount of financial reward received matches the employees' perceptions of justice and fairness, they will seek to maintain a positive relationship with their employer [85]. Employees who have long–term relationships influence the environment with their attitudes and behaviours. In a similar way, their attitudes and behaviours are influenced by their employer [86]. Thus, employees participate in creating the culture and can influence its change. They then have a sense of ownership because they see that their employer is interested in their professional growth, motivation, adequate remuneration, and that they themselves are working for the benefit of the organisation in which they are employed. Furthermore, the results of our survey show that employee commitment has a direct and positive impact on employee satisfaction. This turns out to be an important, albeit different, finding, as previous research suggests that higher levels of satisfaction are associated with a number of benefits, such as improved working conditions, interpersonal relationships, or employer branding [87]. This is consistent with Coyle-Shapiro and Conway and Xiong and collaborators [37,88] who argue that employees feel more job satisfaction when they are more committed in their work.

Our results indicate that the relationship between psychological contract and employee job satisfaction is fully mediated by employees' commitment. Our study indicates that without sufficient commitment, employees are less likely to increase their sense of job satisfaction based on their psychological contract.

In the work context, pro-innovative HR practices are strong predictors of psychological contracting because these shape employee behaviour and are the main mechanisms by which employees understand the terms and conditions of employment [89].

Our results show that implementing pro-innovative HR practices increases employee commitment levels. Although this effect has already been verified theoretically [90], to the best of our knowledge, this study is the first to show this effect evidenced through conducted research. The results achieved appear to be relevant, as the increase in employee commitment is linked to the fulfilment of the psychological contract. Thus, we also found that as pro-innovative HR practices were introduced into the company, the positive impact of psychological contracts improved. This is the first study to examine changes in the strength of psychological contracts due to the implementation of pro-innovative HR practices.

The results of the study presented remain consistent with previous studies which have shown that pro-innovative HR practices appropriately selected in an organization, i.e., training and development [91], reward [22], organization of individual and team work [92], communication [93] and stable employment [94], enhance attitudes of job satisfaction and a sense of fulfilment of the psychological contract. In contrast, the results obtained are contrary to suggestions of other researchers [50,95,96] who pointed that implementing pro-innovative HR practices has negative effects of uncertainty at work and weakens employee commitment.

The pressure to use pro-innovative HR practices contributing to fulfilling SDG 7 and 8 will continue to intensify, whether due to high levels of competitiveness, changing working conditions, or consumer preferences [97,98]. Implementations of pro-innovative HR practices are gaining significant support from top managers and HR professionals, particularly in energy sector organisations. Employees need to feel a sense of fulfilling the psychological contract and be positively committed in the implementation of innovative HR practices in order to fully gain the advantages. Our study shows how employee commitment increases as a result of adopting and implementing pro-innovative HR practices. This study has demonstrated the importance of psychological contracts when introducing pro-innovative HR practices. This means that psychological contracts will play a greater role in shaping the relationship between employers and employees as pro-innovative HR practices spread more widely. Finally, the implementation of pro-innovative HR practices leads to employees fulfilling psychological contracts while being perceived as committed and satisfied with their work, which will move organisations with a particular focus on the energy sector towards achieving SDGs 7 and 8.

5.1. Theoretical Implications

The theoretical contribution of this study is manifested in several aspects. First, we identified relationships between pro-innovative human resource management practices, psychological contract, commitment and job satisfaction. We confirmed that the psychological contract positively influences commitment and that commitment is associated with job satisfaction.

Second, we found that pro-innovative HR practices are a good moderator of this relationship; the introduction of pro-innovative HR practices strengthens the positive relationship between psychological contract and job satisfaction and commitment.

It is also important that this study integrates individual variables (psychological contract) and organizational variables (pro-innovative HR practices) and employee attitudes, which enriches the existing literature on the mechanism of interaction and extends the researchers' theoretical view.

Finally, this study integrates HR practices into a group of pro-innovation practices and assesses employee perceptions of these practices, which demonstrates that HR practices should be analysed holistically rather than as independent practices, because, as Snape and Redman [99] found, they can substitute, complement or interfere with each other in predicting employee behaviour.

5.2. Practical Implications

The completed research also has practical implications. First of all, the results of the research may direct the activities of companies from the energy sector, regarding the search for effective ways of shaping employees' attitudes—commitment and job satisfaction, which may contribute to shaping desired behaviours, including innovative ones. They provide, especially to employees responsible for human resources management, knowledge in the selection of tools and solutions to stimulate commitment and job satisfaction. This may be helpful in developing a more effective human resources management policy. The project also draws attention to the importance of psychological contracts and thus encourages respect for them, as well as the design of HR practices in such a way that employees feel supported by the organisation and reciprocate this support through higher levels of commitment to the organisation's goals.

5.3. Limitations and Further Research

Like most studies, this study also has several limitations. One of the limitations of the study is related to the research methodology used, which was limited to using data from a single source (i.e., reports from employees) through survey methods. Therefore, it would be advisable to conduct further research using, for example, longitudinal studies, which could show a more precise picture of the relationships found and would allow the directions of causality to be explored. Furthermore, the method of data collection may result in a common method bias, which may affect the magnitude of the relationship between the variables under study. To overcome this limitation, all variables were measured using fixed scales, which may reduce measurement error and thus reduce common method bias.

Another limitation stems from the fact that the subject of the study included employees of a single company, albeit thriving in the energy industry. It would therefore be useful to widen the circle of research, which would allow us to establish how these practices are perceived by employees of other energy companies. Moreover, the data were collected in a company operating in specific—Polish—cultural conditions. On the one hand, this may be a limitation of the research, as it narrows the possibility of generalising the results to other countries. On the other hand, however, it provides knowledge on attitudes and behaviours related to the application of pro-innovative HR practices and psychological contracts, characteristic of this cultural circle.

In the course of the research investigation, further interesting research directions also emerged. Firstly, as we focused on employee engagement and satisfaction, it would be worthwhile to widen the circle of research and verify how pro-innovative HR practices and the psychological contract affect other attitudes and behaviours of energy sector employees, e.g., attachment to the organisation. Another interesting direction of research appears to be the analysis of different types of the psychological contract—relational and transactional.

The study was limited to HR professionals of one energy organisation and therefore the results cannot be generalised to other professions. The participants in this study were senior and mid-level HR professionals. Future research recommends including more high-level HR professionals as well as Industry 4.0 experts in the sample to understand the role of HR in Industry 4.0. Future research may seek to use quantitative research methods to validate the findings and conclusions of this study.

6. Conclusions

The issues addressed, supported by the research discussed in the text, made it possible to grasp the relations between the key individual (psychological contract) and organisational (pro-innovative HR practices) variables in a broader perspective, both practical and theoretical. They made it possible to give them a fuller context by capturing the relationships and measuring their strength in a specific way. This justifies the derivation of a positive prognosis as to the topicality of the undertaken issues and the adoption of this research as a starting point for further scientific exploration. Research confirmation of the relationships between these variables may prove useful for organisational practice in enterprises basing their operational and organisational activity on innovative solutions (similarly to the research subject). For the above reasons, the authors remain convinced of the relevance of the undertaken subject matter, its scientific significance and practical usefulness for the functioning of entities operating in the field of modern technological solutions, manifesting their readiness to use innovative organisational solutions, which undoubtedly include energy companies using modern technologies.

Author Contributions: General concept, K.G.-L. and A.R.-P.; theory, K.G.-L. and A.R.-P.; methodology, K.G.-L. and A.R.-P.; validation and formal analysis, A.R.-P.; investigation and data curation, A.R.-P.; preparation of the draft version, K.G.-L. and A.R.-P.; preparation of the final version, K.G.-L. and A.R.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the A.R.-P.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Key Constructs, Subscales and Items

Implementing Pro-innovative HR Practices (IPHRP) [4,5]

(IPHRP I) Personnel pro-innovative activities in the area of employee acquisition related to:

(IPHRP I_1) cooperation with newly recruited employees

(IPHRP I_2) the specificity and nature of one's work

(IPHRP II) Personal pro-innovative activities in the area of professional development related to:

(IPHRP II_1) development opportunities offered by the company

(IPHRP II_2) the implementation of programmes designed to develop high-potential employees (talents)

(IPHRP II_3) flexible and task-based working conditions offered by the company

(IPHRP III) Personal pro-innovative activities in the area of employees' motivation remuneration of related to:

(IPHRP III_1) the remuneration

(IPHRP III_2) the personalised additional package offered (financial and non-financial total rewards)

(IPHRP III_3) the functioning of the performance evaluation system

(IPHRP IV) Personal pro-innovative activities in the area of maintaining positive employee relations related to:

(IPHRP IV_1) maintaining relations and cooperation with employers in the performance of their professional duties

(IPHRP IV_2) maintaining relations and cooperation with co-workers as part of their work on innovative projects

(IPHRP IV_3) opportunities for involvement in decision-making concerning important issues of the company

(IPHRP IV_4) opportunities to create new and innovative products and services for the company's clients

Psychological Contract (PC) [6,7]

(PC I) Fulfilment of the psychological contract by employees towards the employer in the opinion of employees

(PC I_1) Promote and maintain a positive employer branding (company reputation)

(PC I_2) Demonstrate loyalty to the organisation

(PC I_3) Develop new knowledge, skills and experience

(PC I_4) Flexible thinking and proactive approach to solving arising problems

(PC I_5) Be courteous to customers, clients and other colleagues

(PC I_6) Take initiative and put forward new, innovative ideas

(PC I_7) Achieving expected results of strictly defined tasks (hard work for the organisation)

(PC I_8) Maintain high level of attendance and punctuality

(PC I_9) Willingness to work additional hours if the needs of the employer change

(PC II) Fulfilling the psychological contract by the employer towards employees in the employees' opinion

(PC II_1) Opportunities to participate in attractive and innovative trainings, mentoring and opportunities for professional development within the organisation

(PC II_2) Opportunities for promotion within the organisation

(PC II_3) Providing acknowledgement to the employee for initiating and implementing new ideas

(PC II_4) Offering the employee interesting tasks to perform

(PC II_5) Guaranteeing a pleasant and safe working environment

(PC II_6) Ensuring job security and stability

(PC II_7) Providing total rewards commensurate with outputs achieved

(PC II_8) Offering a non-wage benefits package

Employees' Job Satisfaction (EJS)

(EJS 1) I like my job more than the typical employee

(EJS 2) I am enthusiastic about my work most days

(EJS 3) I feel that my work is more interesting than others

Employee Commitment (EC)

(EC 1) I work according to the values of the company

(EC 2) I am happy to be part of the organisation

(EC 3) The organisation where I work encourages me to improve my work performance

References

1. Jędrzejczak-Gas, J.; Barska, A.; Wyrwa, J. Economic Development of the European Union in the Relation of Sustainable Development—Taxonomic Analysis. *Energies* **2021**, *14*, 7488. [CrossRef]
2. Wyzwania Branży Energetycznej w Ramach Zrównoważonego Rozwoju. Available online: https://odpowiedzialnybiznes.pl/wp-content/uploads/2016/10/AnalizaTematyczna_WYZWANIA_BRAN%C5%BBY_ENERGETYCZNEJ.pdf (accessed on 22 November 2021).
3. Riketta, M. The Causal Relation between Job Attitudes and Performance: A Meta-Analysis of Panel Studies. *J. Appl. Psychol.* **2008**, *93*, 472–481. [CrossRef] [PubMed]
4. Ostroff, C. The Relationship between Satisfaction, Attitudes, and Performance: An Organizational Level Analysis. *J. Appl. Psychol.* **1992**, *77*, 963–974. [CrossRef]
5. Harrison, D.A.; Newman, D.A.; Roth, P.L. How important are job attitudes? Meta-analytic comparisons of integrative behavioral outcomes and time sequences. *Acad. Manag. J.* **2006**, *49*, 305–325. [CrossRef]
6. Schaufeli, W.B.; Bakker, A.B. Defining and measuring work engagement: Bringing clarity to the concept. In *Work Engagement: A Handbook of Essential Theory and Research*; Bakker, A.B., Leiter, M.P., Eds.; Psychology Press: London, UK, 2010; pp. 10–24.
7. Rich, B.L.; Lepine, J.A.; Crawford, E.R. Job engagement: Antecedents and effects on job performance. *Acad. Manag. J.* **2010**, *53*, 617–635. [CrossRef]
8. Turek, D. *Destruktywny Kontekst Organizacyjny a Wykonywanie Pracy*; PWN: Warszawa, Poland, 2019.
9. Judge, T.A.; Kammeyer-Mueller, J.D. Job Attitudes. *Annu. Rev. Psychol.* **2012**, *63*, 341–367. [CrossRef] [PubMed]
10. Oshagbemi, T. Overall job satisfaction: How good are single versus multiple-item measures? *J. Manag. Psychol.* **1999**, *14*, 388–403. [CrossRef]

11. Nurperihan, T.; Hatice, U. The relationship of organizational commitment, job satisfaction and burnout on physicians and nurses? *J. Econ. Manag.* **2017**, *28*, 90–111.
12. Robbins, S.P.; Judge, T.A. Power and politics. In *Organizational Behavior*; Parker, D., Collins, J., Eds.; Pearson Education, Inc.: Upper Saddle River, NJ, USA, 2009; pp. 448–481.
13. Evans, W.R.; Davis, W.D. High-Performance Work Systems as an Initiator of Employee Proactivity and Flexible Work Processes. *Organ. Manag. J.* **2015**, *12*, 64–74. [CrossRef]
14. Rakowska, A.; de Juana Espinosa, S.; Mendryk, I. Well-being and job satisfaction of employees aged 50+, perceived organizational support for development and innovation. *Argum. Oeconomica* **2020**, *1*, 143–172. [CrossRef]
15. Rayton, B.A.; Yalabik, Z.Y. Work engagement, psychological contract breach and job satisfaction. *Int. J. Hum. Resour. Manag.* **2014**, *25*, 2382–2400. [CrossRef]
16. Beal, D.J.; Weiss, H.M.; Barros, E.; MacDermid, S.M. An Episodic Process Model of Affective Influences on Performance. *J. Appl. Psychol.* **2005**, *90*, 1054–1068. [CrossRef]
17. Zahoor, S.; Zia, A.; Rizwan, M. Decoding the DNA of Employee Job Satisfaction. *Int. J. Hum. Resour. Manag.* **2014**, *4*, 122–146. [CrossRef]
18. Griffeth, R.W.; Hom, P.W.; Gaertner, S. A Meta-Analysis of Antecedents and Correlates of Employee Turnover: Update, Moderator Tests, and Research Implications for the Next Millennium. *Int. J. Manag.* **2000**, *26*, 463–488. [CrossRef]
19. Cote, S.; Morgan, L.M. A Longitudinal Analysis of the Association between Emotion Regulation, Job Satisfaction, and Intentions to Quit. *J. Organ. Behav.* **2002**, *23*, 947–962. [CrossRef]
20. Mowday, R.T.; Sutton, R.I. Organizational behavior: Linking individuals and groups to organizational contexts. *Annu. Rev. Psychol.* **1993**, *44*, 195–229. [CrossRef] [PubMed]
21. Coetzee, M.; Bester, S.M. Exploring the reciprocal correspondence among workplace relationships, career goal instrumentality, career satisfaction, and organisational commitment. *S. Afr. J. Psychol.* **2020**, *51*, 81–94. [CrossRef]
22. Lv, Z.; Xu, T. Psychological contract breach, high-performance work system and engagement: The mediated effect of person-organization fit. *Int. J. Hum. Resour. Manag.* **2018**, *7–8*, 1257–1284. [CrossRef]
23. Hakanen, J.J.; Perhoniemi, R.; Toppinen-Tanner, S. Positive gain spirals at work: From job resources to work engagement, personal initiative and work-unit innovativeness. *J. Vocat. Behav.* **2008**, *73*, 78–91. [CrossRef]
24. Lewicka, D.; Rakowska, A. Calculative and affective commitment—The case study of the best Polish employer "Gaz Transmission Operator". *Argum. Oeconomica* **2017**, *39*, 213–235. [CrossRef]
25. Christian, M.S.; Garza, A.S.; Slaughter, J.E. Work engagement: A quantitative review and test of its relations with task and contextual performance. *Pers. Psychol.* **2011**, *64*, 89–136. [CrossRef]
26. Freeney, Y.; Fellenz, M. Work Engagement as a Key Driver of Quality of Care: A Study with Midwives. *J. Health Organ. Manag.* **2013**, *27*, 330–349. [CrossRef] [PubMed]
27. Harter, J.K.; Schmidt, F.L.; Asplund, J.W.; Killham, E.A.; Agrawal, S. Causal Impact of Employee Work Perceptions on the Bottom Line of Organizations. *Pers. Psychol. Sci.* **2010**, *5*, 378–389. [CrossRef] [PubMed]
28. Maden, C. Linking high involvement human resource practices to employee proactivity: The role of work engagement and learning goal orientation. *Pers. Rev.* **2015**, *44*, 720–738. [CrossRef]
29. Aggarwal, U.; Bhargava, S. Reviewing the relationship between human resource practices and psychological contract and their impact on employee attitude and behaviours: A conceptual model. *J. Eur. Ind. Train.* **2009**, *33*, 4–31. [CrossRef]
30. Rousseau, D.M. *Psychological Contracts in Organizations: Understanding Written and Unwritten Agreements*; Sage: Newbury Park, CA, USA, 1995.
31. Shore, L.M.; Tetrick, L.E. The Psychological Contract as an Explanatory Framework in the Employment Relationship. In *Trends in Organizational Behavior: Chichester*; Cooper, C.L., Rousseau, D., Eds.; John Wiley and Sons: New York, NY, USA, 1994.
32. Rousseau, D.M.; McLean Parks, J. The contracts of individuals and organizations. In *Research in Organizational Behaviour*; Cummings, L.L., Staw, B.M., Eds.; JAI Press: Greenwich, CT, USA, 1993.
33. Guest, D. Flexible employment contracts, the psychological contract and employee outcomes: An analysis and review of the evidence. *Int. J. Manag. Rev.* **2004**, *5–6*, 1–19. [CrossRef]
34. Rousseau, D.M. Psychological Contracts in the Workplace: Understanding the Ties that Motivate. *Acad. Manag. Exec.* **2004**, *18*, 120–127. [CrossRef]
35. Rogozińska-Pawełczyk, A. *Zarządzanie Zasobami Ludzkimi Oparte na Kontrakcie Psychologicznym*; Wydawnictwo IpiSS: Warszawa, Poland, 2016.
36. Tekleab, A.G.; Laulié, L.; De Vos, A.; De Jong, J.P.; Coyle-Shapiro, J.A.-M. Contextualizing psychological contracts research: A multi-sample study of shared individual psychological contract fulfilment. *Eur. J. Work. Organ.* **2019**, *29*, 279–293. [CrossRef]
37. Xiong, Z.; Ye, J.; Wang, P. Psychological Contract and Turnover Intention of dispatched Employees: Mediating Effects of Job Satisfaction and Organizational Commitment. *Rev. Cercet.* **2017**, *56*, 19–43.
38. Flood, P.C.; Turner, T.; Ramamoorthy, N.; Pearson, J. The causes and consequences of psychological contract among knowledge workers in the high technology and financial services industries. *Int. J. Hum. Resour. Manag.* **2001**, *67*, 845–855. [CrossRef]
39. Lester, S.W.; Kickul, J.R.; Bergmann, T.J. Managing employee perceptions of the psychological contract over time: The role of employer social accounts and contract fulfillment. *J. Organ. Behav.* **2007**, *28*, 191–208. [CrossRef]

40. Diefendorff, J.; Brown, D.; Kamin, A.; Lord, B. Examining the roles of job involvement and work centrality in predicting organizational citizenship behaviours and job performance. *J. Organ. Behav.* **2002**, *23*, 93–108. [CrossRef]
41. Delery, J.; Doty, D. Modes of theorizing on strategic human resource management: Tests of universalistic, contingency, and configurationalistic performance predictions. *Acad. Manag. J.* **1996**, *39*, 802–835.
42. Huselid, M.A. The impact of human resource management practices on turnover, productivity and corporate financial performance. *Acad. Manag. J.* **1995**, *38*, 635–672.
43. El-Ghalayini, Y. Human resource management practices and organizational performance in public sector organization. *J. Bus. Stud. Q.* **2017**, *8*, 65–80.
44. Shantz, A.; Arevshatian, L.; Alfes, K.; Bailey, C. The effects of HRM attributions on emotional exhaustion and mediating roles of job involvement and work overload. *Hum. Resour. Manag. J.* **2016**, *26*, 172–191. [CrossRef]
45. Okabe, N. Interaction of Psychological Contract Violation and Emotional Labour: Recovery of Organizational Trust and Job Satisfaction. In *Applied Psychology Readings*; Leung, M.T., Tan, L.M., Eds.; Springer: Singapore, 2018; pp. 239–261.
46. Papa, A.; Dezi, L.; Gregori, G.L.; Mueller, J.; Miglietta, N. Improving innovation performancethrough knowledge acquisition: The moderating role of employee retention and human resource management practices. *J. Knowl. Manag.* **2018**, *24*, 589–605. [CrossRef]
47. Riana, G.; Suparna, G.I.; Suwandana, G.M.; Kot, S.; Rajiani, I. Human resource management in promoting innovation and organizational performance. *Probl. Perspect. Manag.* **2020**, *18*, 107–118.
48. Katou, A.A.; Budhwar, P.S. The link between HR practices, psychological contract fulfillment, and organizational performance: The case of the Greek service sector. *Thunderbird Int. Bus. Rev.* **2012**, *54*, 793–809. [CrossRef]
49. Rogozińska-Pawełczyk, A. Significance of the psychological contract for the relationship between highly effective HRM systems and employee productivity. *Organ. Manag.* **2019**, *3*, 9–23.
50. Conway, N.; Briner, R.B. *Understanding Psychological Contracts at Work: A Critical Evaluation of Theory and Research*; Oxford University Press: Oxford, UK, 2005.
51. Rousseau, D.M. The individual–organization relationship: The psychological contract. In *Handbook of Industrial/Organizational Psychology*; Zedeck, S., Ed.; American Psychological Association: New York, NY, USA, 2010; pp. 191–220.
52. Rogozińska-Pawełczyk, A. The Effect of HR Practices and Psychological Contract on Employee Performance: The Polish Experience in Business Services Sector (BSS). In *Eurasian Studies in Business and Economics*; Husein, M., Hakan, D., Eds.; Springer: Berlin/Heidelberg, Germany, 2021; pp. 3–20.
53. Crossan, M.M.; Apaydin, M. A multi-dimensional framework of organizational innovation: A systematic review of the literature. *J. Manag. Stud.* **2010**, *47*, 1154–1191. [CrossRef]
54. Kafel, T.; Ziębicki, B. Dynamics of the evolution of the strategic management concept: From the planning school to the neostrategic approach. *Int. J. Entrep. Innov.* **2021**, *17*, 7–28. [CrossRef]
55. Klimas, P. Organisational innovativeness: Its level, building blocks and relationships with interorganisational cooperation inside innovation networks. *Int. J. Bus. Environ.* **2015**, *7*, 373–395. [CrossRef]
56. Oladapo, V.; Onyeaso, G. An Empirical Investigation of Sub Dimensions of High Performance Work Systems that Predict Organizational Innovation. *Int. J. Manag. Mark. Res.* **2013**, *6*, 67–79.
57. Kraśnicka, T.; Glod, W.; Wronka-Pośpiech, M. Management innovation, pro-innovation organisational culture and enterprise performance: Testing the mediation effect. *Rev. Manag. Sci.* **2018**, *12*, 737–769. [CrossRef]
58. Pouwels, I.; Koster, F. Inter-organizational cooperation and organizational innovativeness. A comparative study. *Int. J. Innov. Sci.* **2017**, *9*, 184–204. [CrossRef]
59. Chen, C.J.; Huang, J.W. Strategic Human Resource Practices and Innovation Performance. The Mediating Role of Knowledge Management Capacity. *J. Bus. Res.* **2009**, *62*, 104–114. [CrossRef]
60. Koster, F. Innovative HRM. A Review of the Literature. 2018. Available online: https://doi.org/10.2139/ssrn.3263343 (accessed on 15 November 2021).
61. Grębosz-Krawczyk, M.; Zakrzewska-Bielawska, A.; Glinka, B.; Glińska-Neweś, A. Why Do Consumers Choose Photovoltaic Panels? Identification of the Factors Influencing Consumers' Choice Behavior regarding Photovoltaic Panel Installations. *Energies* **2021**, *14*, 2674. [CrossRef]
62. Groves, R.M.; Fowler, F.J.; Couper, M.P.; Lepkowski, J.M.; Singer, E.; Tourangeau, R. *Survey Methodology*; Wiley: New York, NY, USA, 2011.
63. Podsakoff, P.M.; MacKenzie, S.B.; Podsakoff, N.P. Sources of method bias in social science research and recommendations on how to control it. *Annu. Rev. Psychol.* **2012**, *63*, 539–569. [CrossRef]
64. Drwal, R.Ł. *Adaptacja Kwestionariuszy Osobowości: Wybrane Zagadnienia i Techniki*; Wydawnictwo Naukowe PWN: Warszawa, Polska, 1995; Volume 20.
65. Kinnie, N.; Hutchinson, S.; Purcell, J.; Rayton, B.; Swart, J. Satisfaction with HR practices and commitment to the organisation: Why one size does not fit all. *Hum. Resour. Manag. J.* **2005**, *15*, 9–29. [CrossRef]
66. Wang, K.-L.; Chiang, C.; Tung, C.-M. Integrating human resource management and knowledge management: From the viewpoint of core employees and organizational performance. *Int. J. Organ. Innov.* **2012**, *5*, 109–137.
67. Rousseau, D.M.; Tijoriwala, S.A. Assessing psychological contracts: Issues, alternatives, and types of measures. *J. Organ. Behav.* **1998**, *19*, 679–695. [CrossRef]

68. Guest, D.; Conway, N. Communicating the psychological contract: An employer's perspective. *Hum. Resour. Manag. J.* **2002**, *12*, 22–38. [CrossRef]
69. Bettencourt, L.A.; Gwinner, K.P.; Meuter, M.L. A comparison of attitude, personality and knowledge predictors of service-oriented organizational citizenship behaviors. *J. Appl. Psychol.* **2001**, *86*, 29–41. [CrossRef] [PubMed]
70. MOW International Research Team. *The Meaning of Working*; Academic Press: London, UK, 1987.
71. Saks, A.M. Antecedents and consequences of employee engagement. *J. Manag. Psychol.* **2006**, *21*, 600–619. [CrossRef]
72. De Vaus, D. *Analyzing Social Science Data: 50 Key Problems in Data Analysis*; Sage Publications Ltd.: Thousand Oaks, CA, USA, 2002.
73. Hair, J.F.; Black, B.; Babin, B.; Anderson, R.E. *Multivariate Data Analysis*, 7th ed.; Pearson Prentice Hall: Upper Saddle River, NJ, USA, 2010.
74. Schumacker, R.E. *A Beginner's Guide to Structural Equation Modeling*; Routledge: London, UK, 2012.
75. Fornell, C.; Larcker, D.F. Evaluating structural equation models with unobservable variables and measurement error. *J. Mark. Res.* **1981**, *18*, 39–50. [CrossRef]
76. Sagan, A. *Analiza Ścieżkowa w Badaniach Marketingowych*; Wydawnictwo Uniwerystetu Ekonomicznego w Krakowie: Kraków, Poland, 2018; p. 64.
77. Marsh, H.W.; Hau, K.-T.; Wen, Z. In Search of Golden Rules: Comment on Hypothesis-Testing Approaches to Setting Cutoff Values for Fit Indexes and Dangers in Overgeneralizing Hu and Bentler's 1999. *Struct. Equ. Model.* **2004**, *11*, 320–341. [CrossRef]
78. Hu, L.; Bentler, P.M. Cutoff Criteria for Fit Indexes in Covariance Structure Analysis: Conventional Criteria Versus new Alternatives. *Struct. Equ. Model.* **1999**, *6*, 1–55. [CrossRef]
79. Thakkar, J.J. Introduction to Structural Equation Modelling. In *Studies in Systems, Decision and Control*; Springer: Singapore, 2020; pp. 1–11.
80. Ringle, C.M.; Sarstedt, M.; Straub, D.W. Editor's comments: A critical look at the use of PLS-SEM. *MIS Q.* **2012**, *36*, 3–14. [CrossRef]
81. Khoreva, V.; Wechtler, H. HR practices and employee performance: The mediating role of well-being. *Empl. Relat.* **2018**, *40*, 227–243. [CrossRef]
82. Bal, P.M.; Kooij, D.T.; De Jong, S.B. How do developmental and accommodative HRM enhance employee engagement and commitment? The role of psychological contract and SOC strategies. *J. Manag. Stud.* **2013**, *50*, 545–572. [CrossRef]
83. Chambel, M.J.; Oliveira-Cruz, F. Breach of psychological Contract and the Development of Burnout and Engagement: A Longitudinal Study among Soldiers on a Peacekeeping Mission. *Mil. Psychol.* **2010**, *22*, 110–112. [CrossRef]
84. Jensen, J.M.; Opland, R.A.; Ryan, A.M. Psychological contracts and counterproductive work behaviors: Employee responses to transactional and relational breach. *J. Bus. Psychol.* **2010**, *25*, 555–568. [CrossRef]
85. Rousseau, D.M. Schema, Promise and Mutuality: The Building Blocks of the Psychological Contract. *J. Occup. Organ. Psychol.* **2001**, *74*, 511–541. [CrossRef]
86. Presti, A.L.; Amelia, M.; Briscoe, J.P. Organizational citizenship behaviors in the era of changing employment patterns. The complementary roles of psychological contracts and protean and boundaryless careers. *Career Dev. Int.* **2019**, *24*, 127–145. [CrossRef]
87. Nielsen, B.; Mearns, K.; Matthiesen, B.; Eid, J. Using the Job Demands-Resources model to investigate risk perception, safety climate and job satisfaction in safety critical organizations. *Scand. J. Psychol.* **2011**, *52*, 465–475. [CrossRef]
88. Coyle-Shapiro, J.A.M.; Conway, N. Exchange relationships: An examination of psychological contracts and perceived organizational support. *J. Appl. Psychol.* **2009**, *90*, 774–781. [CrossRef]
89. Peng, K.Z.; Wong, C.; Song, J.L. How Do Chinese Employees React to Psychological Contract Violation? *J. World Bus.* **2016**, *51*, 815–825. [CrossRef]
90. Maheshwari, S.; Vohra, V. Identifying critical HR practices impacting employee perception and commitment during organizational change. *J. Organ. Chang. Manag.* **2015**, *28*, 872–894. [CrossRef]
91. Wangithi, W.; Muceke, N. Effect of Human Resource Management Practices on Psychological Contract in Organizations. *Int. J. Bus. Soc.* **2012**, *3*, 117–122.
92. Van der Smissen, S.; Schalk, R.; Freese, C. Organizational change and the psychological contract. How change influences the perceived fulfillment of obligations. *J. Organ. Chang. Manag.* **2013**, *26*, 1071–1109. [CrossRef]
93. Bal, P.M.; De Lange, A.H.; Zacher, H.; Van der Heijden, B.I.J.M. A lifespan perspective on psychological contracts and their relations with organizational commitment. *Eur. J. Work Organ. Psychol.* **2013**, *22*, 279–292. [CrossRef]
94. Allen, D.G.; Shore, L.M.; Griffeth, R.W. The Role of Perceived Organizational Support and Supportive Human Resource Practices in the Turnover Process. *J. Manag.* **2003**, *29*, 99–118. [CrossRef]
95. Østhus, S. For better or worse? Workplace changes and the health and well-being of Norwegian workers. *Work Employ. Soc.* **2007**, *21*, 731–750. [CrossRef]
96. Nam, T. Technology usage, expected job sustainability, and perceived job insecurity. *Technol. Forecast. Soc. Chang.* **2019**, *138*, 155–165. [CrossRef]

97. Sanders, K.; Shipton, H.; Gomes, J. Is HR process important? Past, current and future challenges. *Hum. Resour. Manag.* **2014**, *53*, 489–503. [CrossRef]
98. Latorre, F.; Ramos, J.; Gracia, F.J.; Tomas, I. How high-commitment HRM relates to PC violation and outcomes: The mediating role of supervisor support and PC fulfilment at individual and organizational levels. *Eur. Manag. J.* **2020**, *38*, 462–476. [CrossRef]
99. Snape, E.; Redman, T. HRM Practices, Organizational Citizenship Behaviour, and Performance: A Multi-Level Analysis. *J. Manag. Stud.* **2010**, *47*, 1219–1247. [CrossRef]

energies

MDPI

Article

Multi-Energy Concern as an Example of the Implementation of Agenda 2030: Poland as a Case Study

Joanna Toborek-Mazur and Magdalena Wójcik-Jurkiewicz *

Department of Accounting, Institute of Management, College of Management Sciences and Quality, Cracow University of Economics, 31-510 Kraków, Poland; toborekj@uek.krakow.pl
* Correspondence: magdalena.wojcik-jurkiewicz@uek.krakow.pl

Abstract: The motive for the functioning of enterprises in the market economy is the maximization of benefits by achieving positive financial results with the minimum possible involvement of capital. The positive results achieved are perceived very positively by the stakeholders. To achieve this, it is necessary to carry out reorganization processes (mergers and acquisitions) within capital groups, which are perceived as necessary (positive) measures. These phenomena have been observed in the energy sector for many years, and the years 2010–2021 were adopted as the research period. The aim of this article is to attempt to answer the question of whether the multi-energy concern is the result of activities carried out in light of the 2030 Agenda. The effect of merging the entities is capital concentration. This fact has been verified by reviewing changes in the structures of capital groups in the energy sector against the background of the largest mergers and acquisitions in Poland in terms of value. The theoretical part presents the differences in the terminology of mergers and acquisitions and the motives for their creation and operation, with an emphasis on energy groups. Therefore, the authors undertook research aimed at identifying and assessing the main premises and effects of capital concentration through mergers and acquisitions in the energy sector in Poland.

Keywords: multi-energy concern; Agenda 2030; the energy sector in Poland; capital concentration; mergers and acquisitions

Citation: Toborek-Mazur, J.; Wójcik-Jurkiewicz, M. Multi-Energy Concern as an Example of the Implementation of Agenda 2030: Poland as a Case Study. *Energies* **2022**, *15*, 1669. https://doi.org/10.3390/en15051669

Academic Editor: Edmundas Kazimieras Zavadskas

Received: 13 December 2021
Accepted: 14 February 2022
Published: 23 February 2022

1. Introduction

Poland, along with nearly 190 other countries around the world, joined the Paris Agreement on climate protection in 2015. The purpose of the agreement is to reduce the negative impact of greenhouse gas emissions on the natural environment by implementing specific solutions on a national (national action plans) and international scale (e.g., providing support to countries in reducing the effects of climate change). During the COP26 (Conference of the Parties) climate summit held in November 2021 in Glasgow, Poland committed to a gradual shift away from coal by the 40s of the 21st century, using, inter alia, the resignation from investments in coal, a just transformation of coal sector employees (on 28 May 2021, a social agreement was signed with miners assuming a schedule for the gradual closure of mines), or an increase in spending on the development of clean technologies [1–3].

An indispensable element that determines the possibility of Poland gaining a competitive advantage in Europe is the concern to ensure an appropriate level of energy security, understood as a guarantee of resistance to any unfavorable and unpredictable events that may threaten the physical integrity of electricity flows. One such unfavorable phenomena may be the limited availability of energy and the possibility of purchasing it at reasonable and acceptable prices. It is worth emphasizing that for many years, the level of energy demand has been increasing, which should encourage the representatives of the authorities to provide an appropriate system for diversifying electricity sources. Preferably, it should be supplied from as many sources as possible and preferably be renewable, thus ensuring adequate flexibility to meet the collective needs of the state [4–6].

The aim of the article is to try to answer the question of whether the multi-energy concern created in Poland is the result of activities carried out in the light of the 2030 Agenda [7–12]. The effect of merging the entities is capital concentration. This fact was verified by reviewing changes in the structures of capital groups in the energy sector against the background of the largest mergers and acquisitions in Poland in terms of value. The analysis of investment motives in the merger processes allowed the authors to refer to the goals and effects of capital concentration in the energy sector.

Mergers and acquisitions are phenomena that are also carried out in the energy system. This system, due to its complexity, as well as economic and geopolitical importance, is an essential link for the development of the economies of many countries [13–15]. This is especially relevant for the post-industrial countries (including Poland), where electricity ensures the functioning of production processes, communication, and trade in goods [16–22].

Creating a concern in the energy system constitutes a big challenge. It can be concluded that this is an energy revolution. The direction of the change has been set, but without defining all the goals.

In the article, the authors analyze the process of establishing energy groups and the creation of a multi-energy concern based on oil, gas, petrochemicals, and energy, which is a response to signed agreements determined by political agreements. Building a new concern will allow for the better management and control of the processes which Poland has committed itself to implement. Its development is ensured by further consolidation within the energy sector. These actions are necessary because market forecasts also indicate that, after 2030, oil consumption will drop significantly in favor of alternative fuels. It is an opportunity to reduce the climate crisis.

Synergy in the economy is a phenomenon consisting of the integration of two or more entities and their activities in such a way that as a result, they would bring greater benefit than if these entities functioned separately. This phenomenon is quite well illustrated by the relation in which 2 + 2 > 4. Due to the use of synergy, it is possible to achieve effects greater than the sum of the results of each of the entities before the merger process. The most important positive results of synergy effects include savings, which are achieved by reducing the duplication of processes, organizational optimization, i.e., more effective use of available resources, as well as financial costs, such as the reduction of costs and tax burdens. An important synergy effect is also complexity, which enables more effective coordination of the activities of internal departments in the company. The synergy effect may be achieved in various areas of the business entity's operation as pure synergy and cost synergy. An example of the latter is the development of a common accounting system (especially management). It is a very important factor in persuading strategic investors to make mergers and acquisitions in 2018–2020 [23].

2. Literature Review

Mergers and acquisitions have been the subject of research by many authors [24–38]. Observations and research have unanimously proven that mergers generally bring positive effects.

Investors very carefully evaluate the market value of functioning economic entities; therefore, mergers and acquisitions may not only lead to capital concentration but also make it easier to obtain it [17]. It is worth noting that this phenomenon is currently the main cause of capital changes in the world [24] pp. 395–399.

In the context of the 2030 Agenda for Sustainable Development, adopting the EU

Renewable Energy Directive and the European Green Deal, the European Union aims for the extremely ambitious goal to become climate neutral by 2050 [7–12].

There are two basic methods of merging companies in the Commercial Companies Code. One of them is an acquisition, and the other is a merger as a method of creating a new company from two existing ones [19]. It should be remembered, however, that both of these methods are fundamentally different from each other, and their use results from specific economic conditions, as well as stakeholders' expectations as to the concept of the development of combined enterprises [31].

Based on accounting reports, many authors prove the positive impact of mergers on the condition of entities participating in these processes. Only the determination of the benefits allows for you to start the connection [39]. The value resulting from this procedure is defined as a significant increase in profitability and as an increase in the value of the combined enterprise [40].

The common denominator of mergers is undoubtedly the pursuit of capital concentration, due to the benefits resulting from increased efficiency in managing the available resources or the synergy effect. Apart from concentration, external development also involves integration (with suppliers or recipients), but also diversification (related and unrelated) [41] p. 19.

The main purpose of the article is to review the changes in the structures of capital groups in the Polish energy sector. The main research hypothesis was the following: the formation of a multi-energy concern is conducive to mergers and acquisitions.

The authors draw attention to the terminological disorder in theory and practice in the nomenclature of various, often different, processes of economic unit mergers. The article uses research methods such as analysis and criticism of the literature and the analysis of financial documents of the studied entities.

In the conducted empirical research, the following research questions will be verified, which at the same time constitute research problems:

Q1: Were there any mergers and acquisitions in the energy sector in the analyzed period, and what were their causes?

Q2: What is the main cause of capital concentration processes in the energy sector, and does it align with Agenda 2030?

Q3: How have the capital structures in the energy sector changed under the influence of these processes?

In addition, the following research hypotheses were put forward:

Hypothesis 1 (H1). *Mergers and acquisitions strengthen a multi-energy concern.*

Hypothesis 2 (H2). *Mergers and acquisitions in the energy sector are processes that increase capital concentration and share in the production and sale of electricity.*

Hypothesis 3 (H3). *Mergers and acquisitions transactions changed the shareholding structure in energy groups and thus increased the influence of the State Treasury during the period considered.*

The global coronavirus pandemic that prevails to this day has caused a disorder of the economic order, for example, by slowing down the economy, causing stagnation in money markets, or, finally, limiting the wealth of investment portfolios of many international companies, which results in a limited capital (resulting from greater investment risk and the need to accumulate capital in a period of uncertainty) economic) with the need to carry out mergers and acquisitions. This is especially visible in the catering, hotel, tourism, and automotive industries [1–3,23]. On the other hand, there is no similar tendency in the energy sector, which prompts the assessment of this phenomenon in this study.

The authors have attempted to evaluate mergers and acquisitions in recent years, paying attention to the acquisition of Energa by Orlen.

3. Theoretical Approaches to Mergers and Acquisitions as a Manifestation of Capital Concentration

The external development of the enterprise as an objective is very important in a dynamic and competitive economy. This development is manifested by business combinations. It is thanks to mergers that companies obtain synergy effects that allow them to implement many new ventures.

A merger is a basic form of merging two separate enterprises into one entity. The distinguishing feature of a merger is that, as a rule, it takes place as a result of the concerted and free action of partners [42].

A merger transaction takes place when the number of companies is reduced as a result of the merger. Such an undertaking can be carried out in two ways. Consolidation (also known as an acquisition sensu stricto) takes place when two entities merge and, in the end, a new economic entity is created. Such a procedure can be presented in the form of the equation [(Subject) A + B = Subject C] [13,14,16]. In general, one could say that "*a merger is defined as a voluntary merger of two business units into a new legal entity under similar conditions for both of the merging entities*" [43].

The second way is attachment (also known as a takeover sensu largo). This situation occurs when one enterprise is liquidated, losing its legal personality, and the assets are bought back. This can be written as [(Subject) A + B = Subject B]. According to the trade law, balance law, and numerous directives of the European Union, it can be called incarnation or incorporation [13,14,16].

The main difference comes down to the statement that two relatively economically equivalent entities are linked by consolidation, while by incorporation, a larger entity (economically, financially, organizationally) incorporates a smaller entity, although it is not an exclusive rule (there are cases reverse) [44–46].

Considering the definitions of an acquisition in a general sense, one can assume, following the dictionary of the Polish language, that it is "*taking what previously belonged to someone else*". It may mean that there is still the same number of things in the physical sense, only some invisible bond between them changes. Similar importance can be noted in economics and management. In management sciences, a merger is defined as a combination of two or more entities, as a result of which all but one of the merging entities lose their legal personality, under the name of which the entity resulting from the merger will function. The merger must be approved by the shareholders or stakeholders, and the merger process itself takes place by way of an exchange of stocks or shares [47].

A comparison of both unit combinations based on the Code of Commercial Companies in Poland is shown in Figure 1.

It can be concluded that the process of economic mergers always results from the merger of two or more companies. In addition, the transaction deprives the other entities of legal personality, as only one of the merger participants retains it. Most of the definitions suggest that the effect of the merger is the creation of a completely new economic entity. Taking into account the fact that the merger increases the resources of the new legal entity, as well as the modification of the organizational structure of the resulting entity, it should be assumed that it is a "new" entity that is the successor of the previously existing entity. Thus, the continued operation of an economic unit under the earlier name does not contradict the condition specified in the other definitions. Although, the functioning of a new entity under the name of an already existing entity is not appropriate, according to the authors. By acquisition, the authors understand the transfer of control from the acquired enterprise to the acquiring enterprise. It often occurs as a result of shareholders accepting an offer to buy their shares. Table 1 presents the most frequently mentioned buyer motives in connection processes.

During the analysis of the above classification, attention should be paid to the financial motives. An interesting example of the implementation of these premises is the separation of a tax group for tax purposes. Such a process is also a merger of several companies. An example is the tax capital group operating in Tauron Polska Energia. In 2011, Tauron completed the registration process of the Tax Capital Group (PGK), which included 11 companies from the capital group. On 14 December 2020, another tax agreement of the capital group for the years 2021–2023 was registered [48].

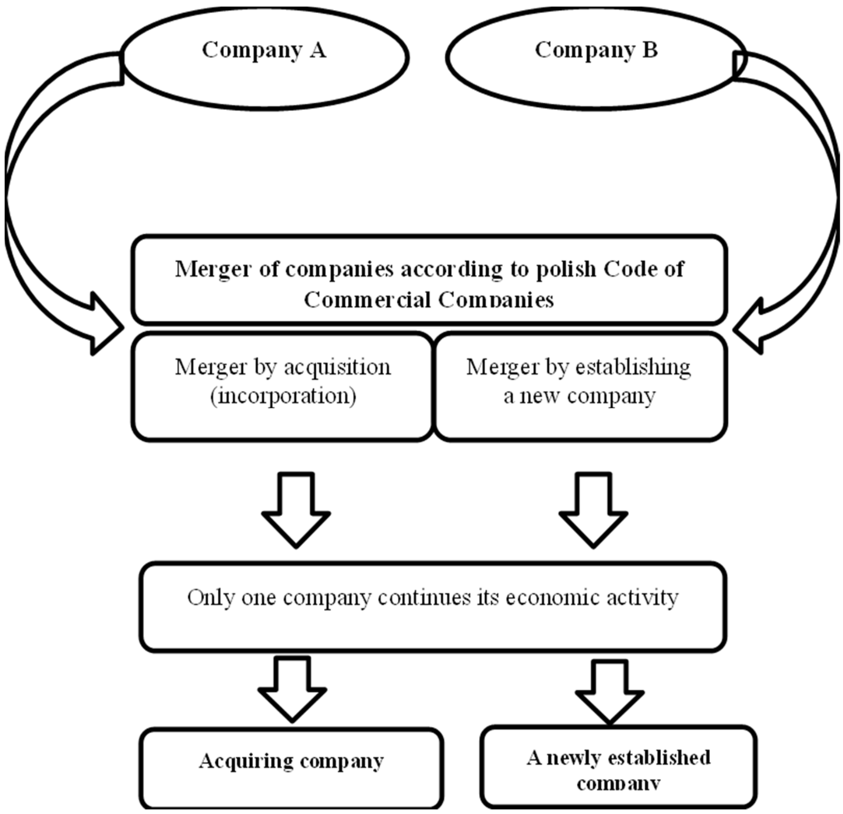


Figure 1. Sample characteristics by Source: author's study based on art. 693 Polish Code of Commercial Companies.

Table 1. Motives for M&A.

No.	Group of Motives	Benefits/Effects
1.	Technical and operational motives	- increasing the efficiency of management, - acquiring more effective management, - firing executives, - operational synergy, - economies of scale, cost reduction.
2.	Market and marketing motives	- increasing market share, - elimination of market competition. - diversification of activities, - entering new areas of activity.
3.	Financial motives	- use of existing surpluses, - increasing debt capacity, - cost of equity reduction, - tax benefits, - underestimation of the value acquired company.
4.	Managerial motives	- increase in management salaries, - increase in prestige and authority, - reduce liability risk, - increasing freedom of activity.

Source: author's study based on: [7,10].

As already noted, the basic difference between a merger and an acquisition is that the former occurs as a result of mutual consent and cooperation between companies.

On the other hand, according to the dictionary of the Polish language, seizure means taking what previously belonged to someone else or detaining someone or something that is on the way illegally. Therefore, takeovers are often considered to be hostile, i.e., those in which the basis is the desire of one of the parties to buy out a controlling stake, without the prior determination of this fact, with the acquired party [13,14,16].

However, due to the closeness of the two terms, merger and acquisition are often used interchangeably, hence distinguishing them in the language of economists is often conventional. Examples of authors who use only one term—"merger"—are Eugene F. Brigham and Louis C. Gapenski in "Financial Management". They explain their choice to use only the term "merger" by the fact that they are solely interested in the process and focus on the fundamental economic and financial aspects of mergers, not the legal ones [49].

The initial years of the regime change in Poland were dominated by the privatization of state-owned enterprises when these entities were massively transformed into limited liability companies [50]. Currently, after thirty years of transformations, interesting changes in the concentration of capital in the mergers and acquisitions market in the energy sector can be observed.

4. The Energy Sector in the Context of Mergers and Acquisitions in Poland

To conduct observations and research, the financial statements of entities participating in mergers and acquisitions from 2010–2020, as well as information from databases, industry reports FORDATA and Navigator Capital and KPMG, the Warsaw Institute of Entrepreneurship, and available studies by the Ministry of State Assets, Internet articles, and press releases were obtained. The first part of this section focuses on capital groups in the energy sector.

The power sector is defined as a part of the fuel and energy sector related to the production, transmission, and distribution of, as well as trading in, electricity and heat. Electricity is the so-called "Base sector", and thus has a significant impact on the development and competitiveness of other areas of the economy in a particular industry [51] p. 53. This has its practical justification because the strong energy demand has been a phenomenon that has been noticeable for many years, not only in Europe but also all over the world. Data transmission via power lines is a pillar of the development of enterprises whose production systems, production automation, or teleinformation services are based on the existence of stable power networks. The power industry currently needs new sources of energy supply. This phenomenon gains additional significance at a time of drastically diminishing natural resources (conventional sources) and the need to search for new, but alternative (unconventional), energy sources.

The assessment was also influenced by the epidemiological situation related to the spread of the SARS-CoV-2 virus on a global scale [52–54]. This event influenced the development of many branches of economies, which, on the one hand, contributed to the improvement of the effectiveness of new distribution and sales channels, and, on the other hand, contributed to the paralysis of those industries that were not able to cope with the new reality. With all these issues in mind, for a more complete understanding of the problem, the authors assessed the situation in the mergers and acquisitions market in 2021 [55–57].

Changes in the energy system are closely related to ensuring energy security, understood as a guarantee of energy supplies and defined as the system's resistance to exceptional and unpredictable events that may threaten the physical integrity of the energy flow or lead to an unstoppable increase in its price, regardless of economic grounds. Therefore, it is part of the national security system because reliable and constant access to energy sources, at costs that can be borne by society, is an essential element of any modern economy. More generally, energy security is such a state of the economy that ensures that the current and future customer demand for fuels and energy is covered in a technically and economically justified manner, with a minimal negative impact of the energy sector on the environment and living conditions of the society.

For many years, a strong multi-energy concern has been created in Poland to meet the challenges related to the energy transformation of Poland. Effective integration within the group through mergers and acquisitions is key to this process. Of course, apart from the basic factors stimulating the achievement of an appropriate level of energy security in Poland, the availability of infrastructure, transport, and, finally, the concentration of suppliers is also important.

The answers to the questions and the verification of the research hypotheses were made based on numerous tables and charts.

The list of mergers and acquisitions in Poland from 2010 to 2019 is presented in Table 2.

As can be seen in Table 2, over the years 2010–2019, the number of mergers and acquisitions has decreased significantly. An important justification for the decreasing number of connections is investment caution resulting from the uncertainty of economic events, and thus difficulties in assessing the long-term prospects of the functioning of enterprises. This problem is more visible in the era of the coronavirus pandemic, which prompts companies to concentrate their accumulated capital rather than make costly business decisions, which undoubtedly include mergers and acquisitions.

Table 2. Merger and acquisitions in Poland from 2010–2019.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
The number of transactions	581	516	331	363	245	223	279	288	323	258
Total value (bln euros)	21	17.5	9	12	8.7	6.3	11.2	10.6	6.5	10.9
The value of the largest transaction (bln zł)	3.0	18.6	4.4	6.2	6.2	2.4	12.7	4.3	4.2	5.0

Source: Raporty M&A Index Polska za Lata 2009–2020, Raporty Branżowe. https://fordata.pl/category/blog/raporty-branzowe, (accessed on 2 July 2021) [58]; M&A Index Poland. Fuzje i przejęcia w 2018 Roku. Raport Przygotowany Przez Firmy Navigator Capital oraz FORDATA Grudzień 2018 Roku. http://www.navigatorcapital.pl/wp-content/uploads/2018/12/Raport_MnAIndexPoland_rok2018_PL.pdf (accessed on 22 November 2021) [58,59].

Continuing the analysis, it can be noted that the number of transactions does not always translate into a correspondingly higher or lower total value of mergers and acquisitions. This regularity can be seen taking into account the years 2010 and 2019. In 2010, with the number of transactions at 581, a total value of mergers and acquisitions was recorded at the level of EUR 21 billion, while in 2019, with only 258 transactions, the total value of transactions was recorded at the level of EUR 10.9 million. These figures illustrate a situation where more costly transactions were made despite a reduced number of transactions in general. In other words, these are, financially, more spectacular operations than single transactions carried out in other years.

From the observations carried out, it can be concluded that the transactions in 2010–2019 were characterized by a much higher value than those from the end of the second decade of the 21st century.

The most valuable connections in Poland from 2010 to 2019 are presented in Table 3.

The largest transaction (from the financial point of view) in the analyzed period was the merger process in 2011, as a result of which Polkomtel acquired Spartan Capital Groups. Its value was estimated at PLN 18.6 billion. In turn, the "cheapest" transaction was carried out in 2015. As a result, the American concern Scripps Network Interactive acquired shares in TVN.

The median of the set of all mergers and acquisitions in 2010–2019 is PLN 4.7 billion. On the other hand, the arithmetic mean is PLN 6.68 billion, and the fashion can be estimated (only with the assumption of rounding to the full value in PLN billion) at PLN 4 billion, with an average deviation of PLN 3.59 billion, and a standard deviation from the population of PLN 4.80 billion. The standard deviation from the sample is PLN 5.06 billion, the range of all values is PLN 16.2 billion, and the statistical error is PLN 1.60 billion. These data also indicate that, in the analyzed years, the value of transactions exceeded PLN 10 billion only in two periods, i.e., in 2011 and 2016. The other transactions individually did not exceed the arithmetic mean of all transactions, amounting to PLN 6.68 billion.

The above results are presented in Table 4.

Table 3. List of the largest mergers and acquisitions in Poland from 2010–2019, in Bln zł.

Years	Transactional Purpose	Buyer	The Value of the Transaction (in Bln zł)
2010	BZ WBK	Bank Santander	3.0
2011	Spartan Capital Holdings	Polkomtel	18.6
2012	Kredyt Bank	BZ WBK (Bank Santander)	4.4
2013	Polkomtel	Cyfrowy Polsat	6.0
2014	Metelem Holding Company Limited	Cyfrowy Polsat	6.2
2015	TVN	Scripps Networks	2.4
2016	Allegro	Cinven, Permira&Mid Europa	12.7
2017	Żabka	CVC Capital Partners	4.3
2018	Unipetrol	PKN Orlen	4.2
2019	DCT Gdańsk	PFR, PSA International & IFM Investors	5.0

Source: Raporty M&A Index Polska za Lata 2009–2020, Raporty Branżowe. https://fordata.pl/category/blog/raporty-branzowe/, (accessed on 2 July 2021) [58]; M&A Index Poland. Fuzje i przejęcia w 2018 Roku. Raport Przygotowany Przez Firmy Navigator Capital oraz FORDATA Grudzień 2018 Roku. http://www.navigatorcapital.pl/wp-content/uploads/2018/12/Raport_MnAIndexPoland_rok2018_PL.pdf (accessed on 22 November 2021) [58,59].

Table 4. Statistical indicators of measures of the largest mergers and acquisitions from 2010–2019.

Statistical Indicator	The Value of the Indicator
Median	4.7 mld zł
Arithmetic average	6.68 mld zł
Modal value	4 mld zł
Average deviation	3.59 mld zł
Standard deviation of the sample	5.06 mld zł
Standard deviation of the population	4.80 mld zł
Value range	16.2 mld zł
Standard error	1.60 mld zł

Source: author's study based on Table 2.

It is certainly important that in the period under review the companies were made intra-group acquisitions. Among others, Polkomtel became part of Cyfrowy Polsat. The former was taken over by Spartan Holdings Capital, and, therefore, the entire venture is owned by Cyfrowy Polsat, which is at the forefront of the telecommunications services market in Poland.

In 2020, a total of 229 mergers and acquisitions were made, so there is still a continuing downward trend in terms of their number. The largest transaction was worth PLN 9.6 billion and concerned the takeover of Play Communications by Iliad S.A. (Fordata, Poznań, Poland, 2020) [59].

A similar phenomenon can be observed in the energy sector. It is one of the most important areas for the development of the economy of many countries. The concern of ensuring an appropriate level of energy security has become the reason for many mergers and acquisitions. The Polish energy economy is based primarily on fossil fuels. According to 2011 data from the Ministry of Economy, the share of coal in the primary energy demand structure is the highest and amounts to 56%. It is followed by crude oil (25%), natural gas (13%), and biomass and waste (6%), respectively.

Figure 2 shows the structure of primary energy demand by source.

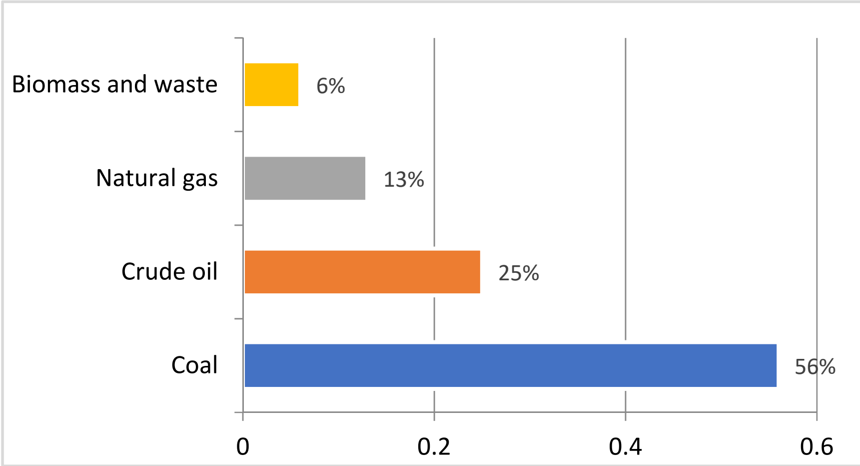


Figure 2. The structure of primary energy demand is classified. Source: author's study based on report "Raport sektorowy—energetyka", by Jan Sekuła posted 31 October 2021, https://profit-journal.pl/raport-sektorowy-energetyka/ access date: 2 February 2022 [60]; bankier.pl [37] (accessed on 23 November 2021).

This state of affairs is largely due to the geographical location of Poland. It has large stores of fossil fuels, mainly hard coal and lignite. According to data from Agencja Rynku Energii S.A. in August 2020 [61], the total share of hard coal and lignite in the structure of consumption of basic fuels in the commercial power industry in the period of January–August 2020 (a decrease by about 2 percentage points compared to the corresponding period in 2019) amounted to nearly 87.8%, while the share of gaseous fuels was only 6.87% (an increase by 1 percentage point compared to the corresponding period in 2019). Admittedly, the share of biogas/biomass also increased from 3.92% in 2019 to 5.10% in 2020.

The analysis of the above values leads to a thesis that, currently, Poland is not a sufficiently independent recipient of energy sources because the production of electricity is still largely based on coal (hard and lignite).

According to the analysis of the National Energy and Climate Plans (NECP), Poland is among the 7 EU countries that are the most delayed in the implementation of the coal transition program [62,63]—and by 2030 it is to be the most coal-dependent country in the community. From a long-term perspective, this approach requires a fundamental change [64,65]. This is dictated not only by the growing awareness of the need to protect the natural environment (in the context of limited non-renewable energy resources), but also by the current legislative trends in the European Union. Poland's independence from fossil fuels will not only positively contribute to the improvement of the quality of the natural environment (including polluted air), but should also allow for the building of an appropriate level of energy security.

Renewable energy sources are at the forefront of solutions aimed at reducing the unfavorable share of fossil fuels in the structure of electricity demand in Poland. The gradual growing share of renewable sources in this structure should be considered a positive effect of the current legal and social trends, the final result of which is the need to become independent from non-renewable sources. For comparison, at the end of August 2021, the capacity of installed renewable energy sources increased, compared to the same period from 2020, by 33.9%, amounting to 14.9 GW. Therefore, taking into account the total capacity of all installed electricity sources in Poland (approximately 53.4 GW), the share of renewable sources is nearly 28%. The largest share of the available renewable sources in Poland is wind farms at around 6790 MW and photovoltaics at 5970.8 MW. Table 5 presents a detailed summary of the given types of electricity sources, with an installed capacity in MW, in August 2021 [66].

Table 5. Types of energy sources in Poland as of 30 August 2021.

Type of Renewable Source	Installed Capacity in MW
Wind power plants	6790.7
Photovoltaics	5970.8
Hydroelectric power stations	976.4
Biomass power plant	907.5
Biogas power plants	256.4
Total value	14,901.9

Source: The types of energy sources in Poland as of 30 August 2021. Source: author's study based on report "Raport sektorowy—energetyka", by Jan Sekuła posted 31 October 2021, https://profit-journal.pl/raport-sektorowy-energetyka/, access date: 2 February 2022 [60]; bankier.pl (accessed on 23 November 2021).

Aside from the above considerations, it is worth noting that another solution proposed by the experts is the transition to nuclear energy, which will accelerate the process of decarbonizing Poland's energy structure and thus contribute to the improvement of the country's energy security [67–69].

Although many different entities in Poland have a license to trade in electricity, the entire energy market is divided into 4 entities, which end suppliers choose depending on their geographic location. When characterizing this sector, it should be mentioned that under the government program, four capital groups (the so-called big energy four) were created: PGE, Tauron, Enea, and Energa, which generate about 70% of the country's energy. In addition, Innogy Polska, which manages the capital's electricity network, runs its business in Warsaw.

The goal of the government program, which is to consolidate the Polish energy market, is implemented by linking economically strong enterprises. As a result of this consolidation, these entities will be able to incur investment costs, compete, and balance the energy market.

In the first stage, the Transmission System Operator was separated from the structures of PSE (PSE Operator) and Distribution System Operators (including energy companies, e.g., ZKE Dystrybucja, RWE Stoen Operator, etc.) as independent legal entities [70]. The Transmission System Operator, along with the transmission network, has been handed over to the State Treasury. In turn, PSE was merged with the Polish Energy Group, which is one of the four energy groups operating on the market.

Polska Grupa Energetyczna (PGE) was established on the basis of the BOT Górnictwo i Energetyka SA holding, Zespół Elektrowni Dolna Odra SA, with the assets remaining after the separation of the Transmission System Operator from PSE SA, along with its assets and 8 distribution companies from central and eastern Poland without RWE Stoen.

An important entity forming the energy sector is Tauron Polska Energia SA. It is the second-largest enterprise in Poland after Polska Grupa Energetyczna. It is a joint-stock company listed on the Warsaw Stock Exchange since 2010. The Tauron Group is one of the largest economic entities in Poland and is one of the largest energy holdings in Central and Eastern Europe. It operates in all areas of the energy market, from coal mining, to the generation, distribution, and sale of electricity and heat, as well as customer service. On a smaller scale, the holding also conducts the wholesale of fuels and derivative products (trading in coal and biomass). In 2014, Tauron entered the gas fuel trading market. Currently, it is active in the field of renewable energy sources.

Another energy group is Enea. According to the government program, this group included companies under privatization or consolidation. Enea S.A. is a parent company that operates in the full value chain of the energy market: hard coal mining, electricity generation, electricity distribution, and energy trading. The Group also operates in the area of heat generation, distribution, and sale, as well as in the field of lighting services. It is the vice-leader in electricity production in Poland. In 2018, it generated 26.5 TWh. It was created from the merger of five power plants (Poznań, Bydgoszcz, Szczecin, Zielona Góra, and Gorzów Wielkopolski), as well as from subsequent acquisitions (including the Kozienice Power Plant and Połaniec Power Plant).

Energa SA is a group that produces and sells thermal and electric energy as well as gas. Currently, after the acquisition by PKN ORLEN S.A., which holds 80.01% of its share capital, the main activities of the group include the generation, distribution, and trade in electricity and heat. The Gdańsk entity has the largest share of RES in energy production among all Polish energy groups (over 40%). The production capacities include a system power plant in Ostrołęka, two combined heat and power plants, forty-seven hydropower plants, a pumped-storage power plant, five wind farms, and two photovoltaic farms. The Group's distribution network covers an area of approximately 1/4 of the country [71].

The creation of a multi-energy concern favors mergers and acquisitions. There are also other companies in Poland operating within the energy sector, the market values of which are shown in Table 6.

It is worth mentioning that the ownership structure of other holdings is different from the above-mentioned four Polish energy groups. The owner of the ČEZ group, whose capitalization is the highest and exceeds PLN 40 billion, is the Czech Republic, which holds 69.78% of the property rights [72]. The volume share of the produced energy for each company is presented in Figure 3.

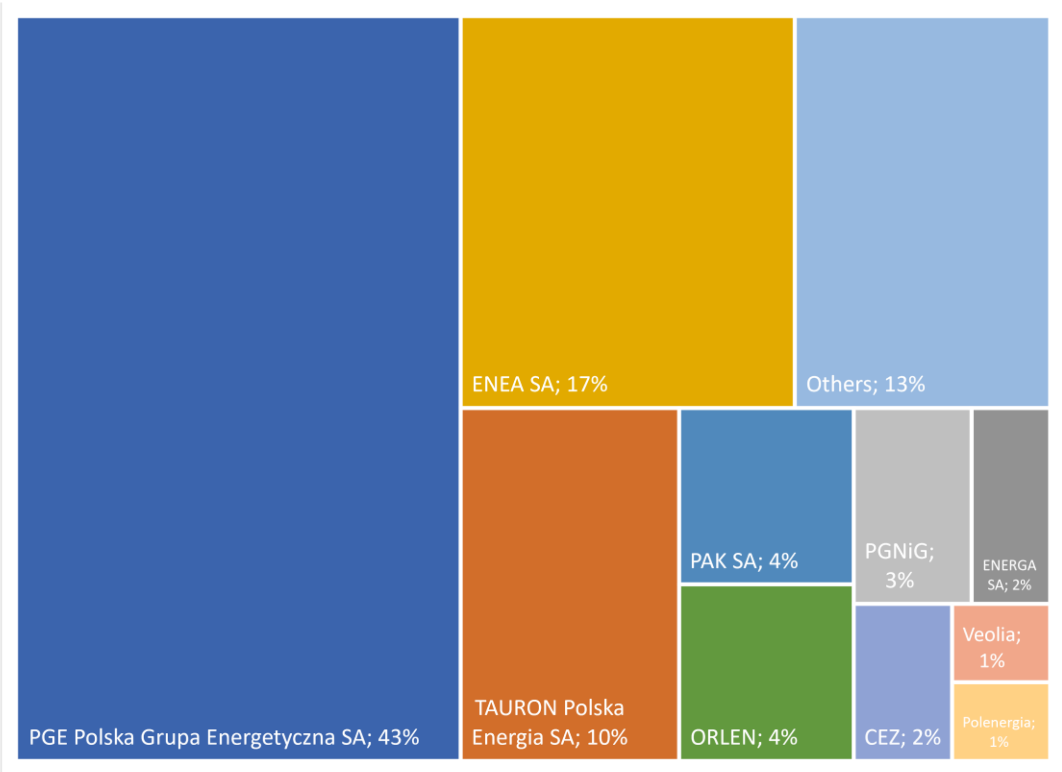


Figure 3. Share of capital groups in the volume of electricity fed into the grid in 2021. Source: author's study based on: https://profit-journal.pl/raport-sektorowy-energetyka/ (access date: 15 August 2021) [60]; bankier.pl (accessed on 23 November 2021).

Table 6. Energy groups in the energy sector in Poland.

Company Name	Market Capitalization in zł	Company Name	Market Capitalization in zł
CEZ	4,034,923,192,500	POLENERGIA	189,045,155,520
PGE	820,825,003,931	AB INTER RAO	29,200,000,000
TAURON	299,685,946,374	KOGENERACJA	45,594,000,000
ENEA	198,649,160,100	ZEPAK	46,757,663,240
ENERGA	343,882,738,177	ML SYSTEM	39,683,593,780

Source: author's study based on: https://profit-journal.pl/raport-sektorowy-energetyka/ (access date: 15 August 2021) [60]; bankier.pl (accessed on 23 November 2021).

Polska Grupa Energetyczna (PGE S.A.), as confirmed by the chart above, supplies over 40% of the energy for the entire country. This means that the share of this group in the structure of diversification of electricity supplies in Poland is significant, and may, in the long term, contribute to a significant concentration of energy capital in the hands of the State Treasury. Due to their strategic nature for the development of the economy, the largest Polish energy companies have a majority share of the State Treasury in their shareholding structure. The state's share in PGE is 57.39%, is 54.49% in Tauron Polska Energia, and is 51.5% in Enea [73].

The exception among large Polish companies is Energa in Gdańsk, for which the majority shareholder is PKN Orlen. It is worth noting that PKN Orlen itself holds over 27% of the State Treasury's share in the shareholding structure.

5. Multi-Energy Concern—A Case Study from Poland (PKN Orlen and Energa)

The largest acquisition of the Polish fuel and energy market is the purchase of 80% of shares in Energa Group by PKN ORLEN. This means that the concern owns the Gdansk-based company. The purchase process was completed in just 4 months. PKN ORLEN announced a tender offer for 100% of Energa Group shares on 5 December 2019. Due to, among other things, the situation caused by the COVID-19 outbreak, the time for accepting subscriptions for shares in the Pomeranian group has been extended until 22 April 2020. The concern received approval from the European Commission for the transaction on 31 March 2020 [74]. The transaction was finalized on 30 April 2020, with the acquisition of Energa shares representing approximately 80% of the company's share capital and approximately 85% of the total number of votes at the general meeting. The price of all shares acquired amounted to approximately PLN 2.77 billion and was covered by the company with cash from its resources and an available syndicated loan [75]. The financial results of Energa before the merger with PKN ORLEN are presented in Figure 4.

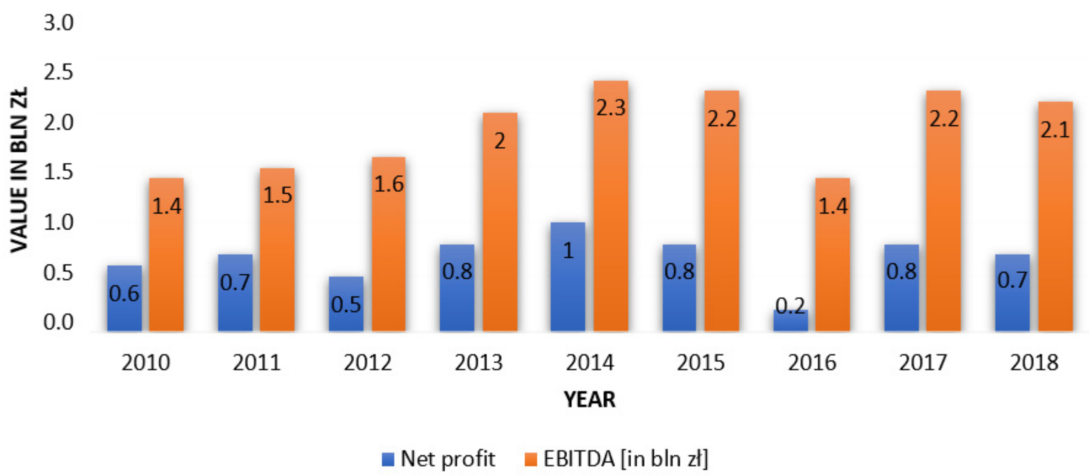


Figure 4. Financial results of the Energa group from 2010–2018. Source: author's study based on https://wysokienapiecie.pl/24792-orlen-chce-przejac-energe/ (access date: 15 August 2021).

As can be seen from the chart, even though the EBITDA [76] value of the Gdansk-based Group did not change in recent years before the merger transaction, the market value of the Group dropped significantly. In 2015, the market value of Energa is almost PLN 11.5 billion. The following years brought a significant reduction in the market capitalization of the acquired company. First and foremost, misguided investment activities contributed to this valuation, which resulted in a liquidity crunch for the acquired company.

When analyzing Energa Group's financial results for 2019, it is worth noting the significant reduction in operating profit, which amounted to PLN 459 million compared to PLN 1.18 billion in the previous year. EBITDA was PLN 2.04 billion compared to PLN 1.88 billion a year earlier. The Energa Group suffered a net loss of PLN 1 billion in 2019, compared to PLN 744 million profit for 2018, and the reason for the company's declining market capitalization is visible. The group's parent company's net loss for 2019 is PLN 952 million. It is worth mentioning that the company ended 2018 with a profit of PLN 739 million [77]. A decrease in the market value of Energa before the merger with PKN ORLEN is shown in Figure 5.

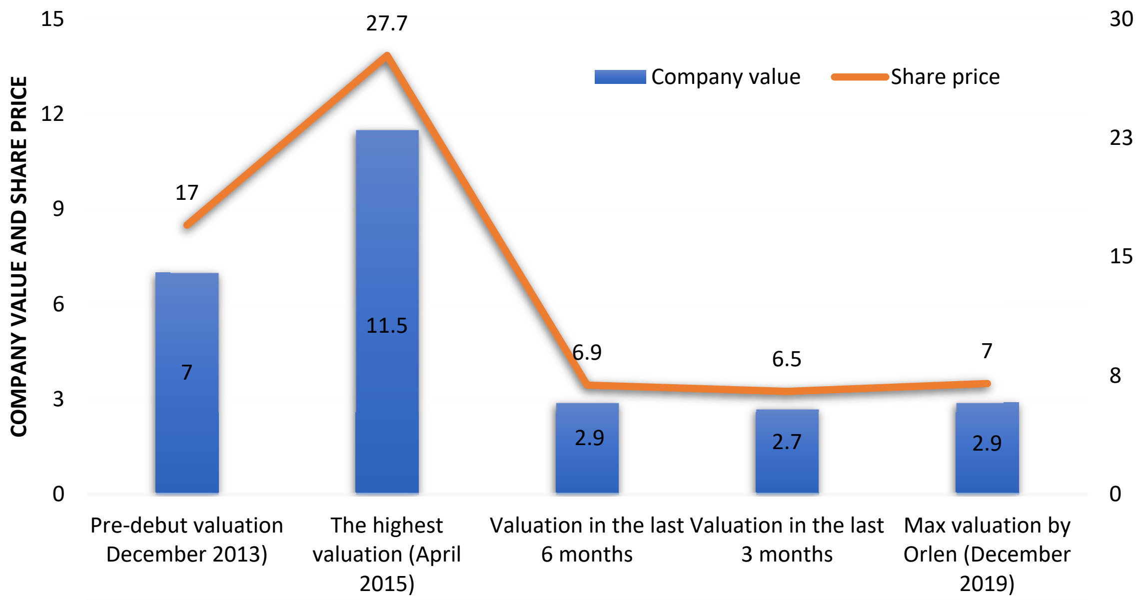


Figure 5. Market value of the Energa concern before the merger by PKN ORLEN. Source: author's study based on https://wysokienapiecie.pl/24792-orlen-chce-przejac-energe/ (access date: 15 August 2021).

Negative financial results of the Energa group were significantly influenced by the impairment test conducted by Ostrołęka power plant and recognition of impairment loss for PLN 1.03 billion, as well as an impairment loss on PGG shares and recognition of a provision for future tax liabilities. It was the investment related to the construction of a new coal unit in the Ostrołęka Power Plant that so significantly reduced the value of the acquired group [78]. That is why PKN Orlen offered a maximum of PLN 2.9 billion for the buyout. Orlen's current capitalization is PLN 37.5 billion.

The next charts show the energy market share of Polish energy companies after the merger of PKN ORLEN and Energa Group and their impact on sales to end-users. The analysis of the graphs clearly shows that the transaction has strengthened the energy concern and changed its structure, as presented in Figure 6.

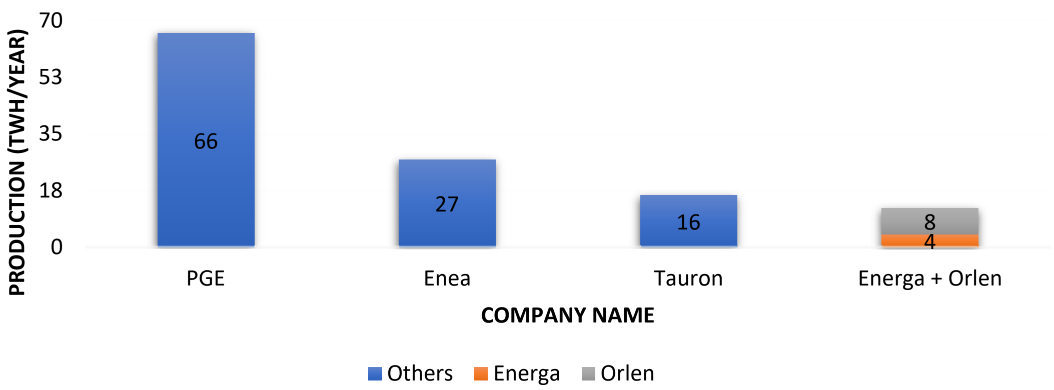


Figure 6. Electricity market after Energa acquisition by Orlen–production [TWh/Year]. Source: author's study based on: https://wysokienapiecie.pl/24792-orlen-chce-przejac-energe/ (access date: 15 August 2021).

From this analysis, we can see the increasing share of merged entities in the energy market. This supports research hypothesis no. 2.

The market objective of the concentration in the multi-energy sector is to gain an appropriate competitive advantage through the diversification of revenue sources, which not only allows for the building of additional value for customers, but primarily serves to create an appropriate level of resistance of the company to market fluctuations. Finally, it should be noted that Energa Group owns a wide range of assets for acquiring renewable energy sources, including, among others, wind farms and hydroelectric power plants. On the other hand, by using PKN Orlen's production surpluses, it is possible to reduce operating costs, and the combined customer base will generate additional sales potential. Figure 7 clearly shows the increased energy market share (sales to end users) of the two combined entities. This supports research hypothesis no. 2.

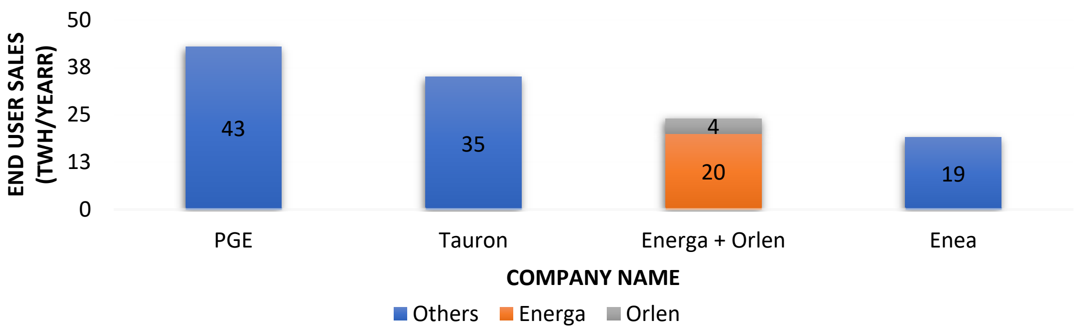


Figure 7. Electricity market after Energa acquisition by Orlen-end-user sales [TWh/Year]. Source: author's study based on: https://wysokienapiecie.pl/24792-orlen-chce-przejac-energe/ (access date: 15 August 2021).

The multi-energy concern that is being created will likely more easily meet the challenges of Poland's energy transformation. The effective concentration of capital within the Group is critical to this process. Therefore, PKN ORLEN initially wanted to purchase 100% of Energa group shares. Such capital control always means tangible benefits both organizationally and operationally. Although control has not been fully acquired, the participation of the remaining shareholders does not jeopardize the strategic objectives set by the acquirer [79].

According to the authors, this merger is another important stage in the creation of a strong, multi-energy concern that will strengthen the competitive and financial position of the participating entities, as well as the country's energy security and, consequently, the Polish economy (Hypothesis 1). These conclusions are also confirmed by other analysts (Polish Multi-energy concern, March 2021).

PKN ORLEN has announced a tender offer for a minority stake in Energa S.A. This will further facilitate the effective integration of the assets of ORLEN and Energa Groups. It will also bring tangible benefits to ORLEN Group shareholders and investors, who will be able to fully benefit from the synergies of the merger. It is worth remembering that the purchase alone does not complete the effective integration of the two entities, which sometimes takes several years, especially since the transaction itself was completed in a very short time.

The company plans to develop the areas in which Orlen and Energa are already active, such as renewable energy and electromobility, but also to enter new projects, such as offshore wind farms. The completion of this transaction should result in a more efficient use of the companies' combined potential. The group owns more than 50 assets that produce energy from renewable sources, primarily including hydroelectric power plants, onshore wind farms, and photovoltaic farms. More than 30% of the electricity produced by the Energa Group comes from renewable sources and this is the highest share among its main competitors. For PKN ORLEN, it is an interesting RES portfolio that balances the company's conventional assets, such as the steam-gas units in Płock and Włocławek. Additionally, the diversification of revenue sources increases the company's resilience to market fluctuations and changes in the macroeconomic environment. In this way, additional value is built for customers and shareholders.

The authors believe that the merger of these entities will not only benefit both companies, but the entire Polish economy. The beneficiaries of the capital takeover of the Gdansk group are also Pomerania and its inhabitants. Thanks to the planned investments, the number and scale of orders will increase. From a fiscal point of view, Energa will remain fully separate, which means more income for the local government budget and influence over the development of the Pomeranian area. Shares of companies in the WIG-ENERGIA index after the merger are illustrated in Figure 8.

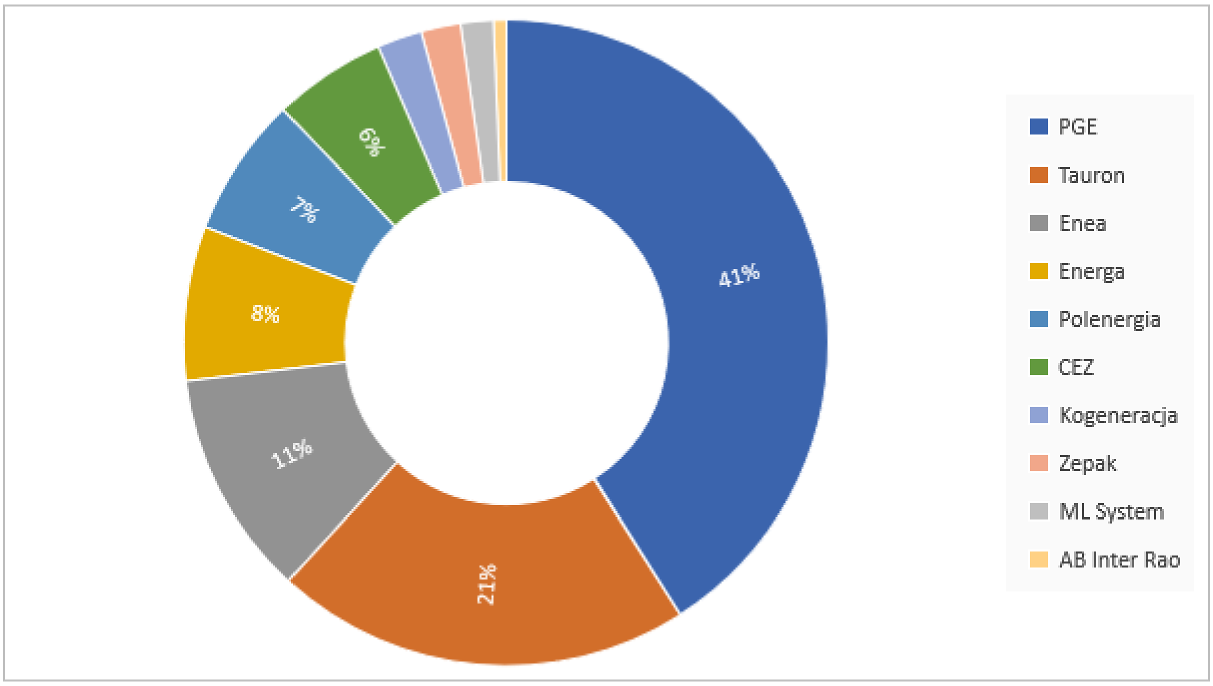


Figure 8. Shares of companies in the WIG-ENERGIA index as of 30 October 2020. Source: author's study based on: https://profit-journal.pl/raport-sektorowy-energetyka/ access date: 25 August 2021 [60]; bankier.pl (accessed on 23 November 2021).

According to Figure 8, the largest share in the companies' structure in the WIG-Energia index on 30 October 2020 was in PGE S.A. and amounted to 40.93%. Tauron is in second place with a result of approximately 20.88%. The next two largest shares include Enea at 11.29% and Energa at 7.74%. These data only confirm the thesis that among many entities in the energy market, only the 4 largest entities forming the concern play a key role in ensuring an appropriate level of energy security. This supports research hypothesis no. 3.

6. Top Motives for Acquisitions and Mergers by Investors in the Energy Sector

The motives behind mergers and acquisitions are varied. Many authors point out that investment motives vary depending on the type of entity that conducts the transactions. Strategic investors who acquire companies want to integrate the entity with the rest of the group and have a real impact on its management. Financial investors, in turn, involve capital in an entity, expecting economic benefits from its future sale.

In a survey conducted by KPMG, both strategic and financial investors took part. In response to investment motives, strategic investors most often indicated the willingness to expand geographically and take over the portfolio of products and services (79% of responses) as the main or the most frequently considered reason for the investment.

Figure 9 illustrates the main M and A motives listed by investors.

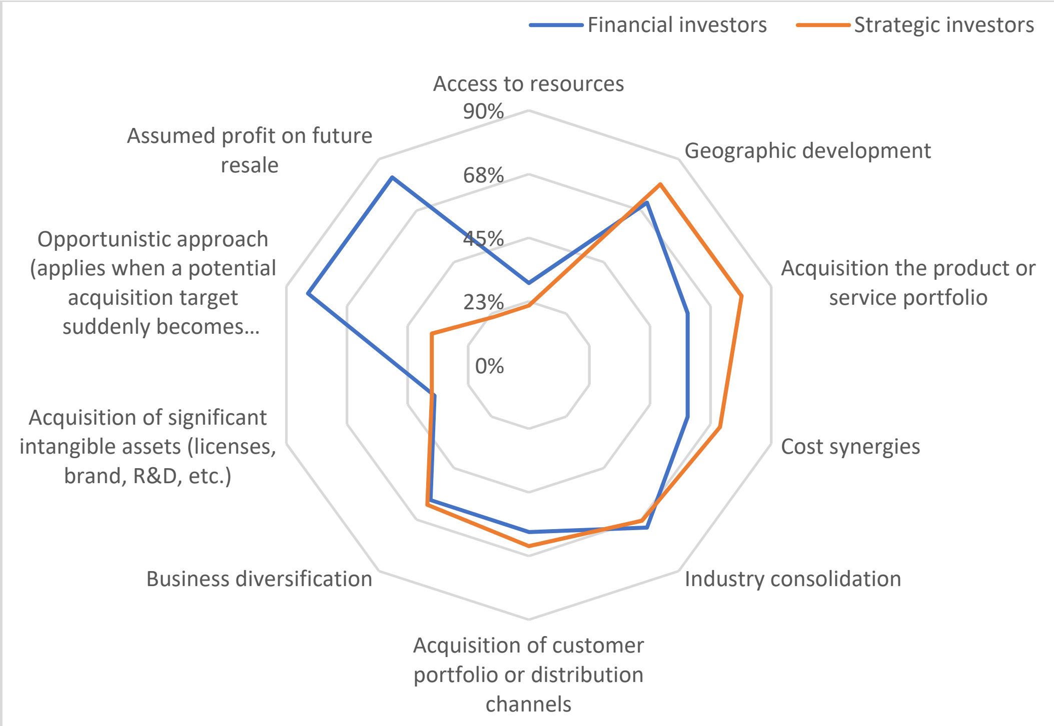


Figure 9. Main investment motives in mergers and acquisitions. Source: author's study based on report "Charakterystyka procesów transakcyjnych w Polsce. Oczekiwania a rzeczywistość", KPMG, Warszawa 2021, p. 13.

Cost synergies of industry consolidation and acquisition of customers and distribution channels are also important to them. Almost 80% of strategic investors (Figure 9), when making an equity investment, do not consider the subsequent resale of the object of the transaction to make a profit on such a transaction. However, the vast majority of financial investors (82%) say that the main or usually considered factor when making a transaction is the desire to profit from the future resale of the entity. The vast majority of financial investors (82%) say that the primary or usually considered factor in making a transaction is the desire to profit from the future resale of the entity. In addition, more than two-thirds are making acquisitions to consolidate the industry. Table 7 presents the distance between investment motives in M and A.

As can be seen by analyzing Table 7, both strategic and financial investors are driven by similar motives in M and A transactions. However, because of their expectations, their importance is different. A strategic investor looking to integrate an entity expects to realize the benefits of capital and personnel ties. When a financial investor involves capital in an entity, they expect quick economic benefits from its future sale. In many aspects, a certain degree of agreement between the two investor groups can be observed, e.g., on the issue of access to raw materials, acquisition of significant intangible assets, business diversification, acquisition of customer portfolio or distribution channels, and industry consolidation. However, the biggest differences between investors are in the issues of expected return on investment or the success of the acquisition target. A very important motive for both groups of investors (having an arithmetic mean of 0.7) is the consolidation of the industry, which is confirmed by the process of strengthening the multi-energy concern (Hypothesis 1).

Table 7. Distance between investment motives in mergers and acquisitions undertaken by financial and strategic investors.

Factor—Category	The Importance of the Category for the Financial Investor	The Importance of the Category for the Strategic Investor	The Importance of Category for both Groups of Investors (Arithmetic Mean)
Access to resources	0.3	0.3	0.3
Assumed profit on future resale	0.8	0.3	0.55
Opportunistic approach (applies when a potential acquisition target suddenly becomes available)	0.8	0.3	0.55
Acquisition of significant intangible assets (licenses, brand, R&D, etc.)	0.3	0.3	0.3
Business diversification	0.6	0.6	0.6
Acquisition of customer portfolio or distribution channels	0.6	0.6	0.6
Industry consolidation	0.7	0.7	0.7
Cost synergies	0.6	0.7	0.65
Geographic development	0.7	0.8	0.75

Source: author's study based on Figure 9.

7. Discussion

Analyzing the program of creating a multi-energy concern in Poland, one can confirm that its transformational goals are ambitious. PGE has announced that it will achieve climate neutrality by 2050 by acquiring 20 gigawatts (GW) of power from renewable energy sources. Currently, the company's total installed capacity is 17 GW and it is received mainly from coal assets. The three directions of development for the next decade—offshore, onshore, and photovoltaic—are expected to contribute to achieving this goal. Particularly interesting news for the energy industry was coming out in the second quarter of 2021. Namely, the Ministry of State Assets plans to consolidate the incumbent on energy companies mining assets and create a new entity. We are talking about the planned spin-off of coal assets from the Treasury's energy companies.

The separation of selected assets also has a practical justification. Other companies that have suffered as a result of the financial crisis caused by the COVID-19 pandemic are also using such strategies. They take defensive and offensive tools that optimize the internal investment portfolio.

Among the most important defensive activities of M and A operations are the possibility of selling some part of ineffective assets. Another solution is the ability to look for strategic partnerships and alliances with other market players as part of mergers and acquisitions [80].

This strategy is in line with trends in the global energy industry, where asset stripping can be seen due to shrinking synergies between areas of the value chain. Sellers conclude that disposing of less desirable assets is more profitable than the gains from owning them.

An example of such an activity is the sale of the REN power grid operator as part of Portugal's Stabilization and Growth Program. There is a closing of investment cycles by financial investors. Thus, Private Equity investors who made investments in the electricity market in previous years are choosing to realize profits and sell selected assets from their portfolios. The sale of AES Red Oak LLC, an electricity generator, by U.S. fund PE Energy Capital Partners LLC is one of many such deals [81].

The proposed actions of the Ministry of State Assets in Poland will improve the profitability of these companies and allow for new sources of financing for RES investments. They will be able to obtain bank loans more easily.

The news about removing mines from power companies will probably be well valued by the market, which can be seen from the charts of all the power companies, especially Tauron, whose subsidiary Tauron Wydobycie generated almost PLN 84 million in losses on

PLN 236 million revenue in Q1 2021 alone. According to PGE's CEO, the optimal date for spinning off coal assets from current energy groups is the end of 2021. According to the authors, the fact of this announcement should positively influence the improvement of the financial results of these companies [82].

It is worth emphasizing that the accelerated monopolization of the energy sector by state-owned corporations will probably result in a significant increase in energy prices in the future, with simultaneous attempts to interfere in the system of rates and charges, e.g., by offering compensations or the possibility of postponing the increase in gas prices for households. This result is compounded simultaneously by several important factors. First, in 2021, a power fee was introduced, charged to final energy consumers for financing new or the modernization of existing units by power companies. Second, the effects resulting from the prevailing global coronavirus pandemic have been severe on the economy as a whole—demand for energy and gas has increased after the lockdown period. Additionally, there is a shift developing in Europe from traditional fuels to renewable sources. Finally, the effect of Russia's unpredictable gas policy, which seeks to maintain its influence in EU states, if only by exerting pressure on the start-up of the Nord Stream 2 pipeline [83].

8. Conclusions

Continuing the discussion, it is worth mentioning the next steps in strengthening the multi-energy concern. Currently, there are plans to merge three state-owned holding companies [84]. On 12 May 2021, a cooperation agreement was signed between PKN Orlen and Lotos Group, PGNiG, and the State Treasury concerning the acquisition of control by the Płock concern over its competitor from Gdańsk and PGNiG. As a result of this transaction, all assets of the acquired companies will be transferred to PKN Orlen. The State Treasury and PKN Orlen will work together to develop analyses aimed at the final confirmation of this scenario as optimal from the point of view of the State Treasury [85].

The agreement executed between the parties of the transaction postulates that, as a result of the merger, shareholders of the Lotos Group and PGNiG will receive new shares issued by Orlen in exchange for their shares. This will occur when it assumes the rights and obligations of the Lotos Group and PGNiG, respectively, under universal succession. The State Treasury will increase its shareholding in the entity created as a result of the acquisition of Lotos and PGNiG by PKN Orlen to 50%, which will protect it against hostile takeovers. The acquisition by Orlen will be non-cash and the State Treasury's stake in PKN Orlen will be increased. They are currently below 30% [79]. These are further facts that will support the accepted theses in this paper.

In July 2021, the Ministry of State Assets announced the planned merger of three energy companies—PGE, Tauron, and Enea—in the coming years. The strategy related to the divestment of coal mines from the assets of energy companies is very important due to the inevitable transition towards green energy and the resulting preferential conditions for raising capital from banks and EU programs [86]. This type of financing is essential for the implementation of the long-term energy transition process, which aims for a 55% reduction in Poland's emissions at an estimated cost of €136 billion [68]. This fact fully confirms that the strengthened multi-energy concern can contribute to the implementation of activities carried out in light of the 2030 Agenda. Thus, it can be considered that the scale of M and A transactions in the sector, which take place in the energy sector are due to signed agreements and are the result of actions carried out in light of the 2030 Agenda [7–12].

Summarizing the considerations, it can be concluded that the transferred transactions of capital concentration significantly increase the participation of the Treasury in energy companies and contribute to ensuring national energy security. These processes strengthen the multi-energy concern and reduce the number of capital groups that are operators of energy services in the country. A strengthened concern arguably has more investment potential. In turn, entering an integrated holding company is a major development opportunity for any entity. The creation of multi-energy concerns is in line with megatrends and actions implemented by other, international oil companies. An example of such a state-controlled multi-sector conglomerate is Italy's ENI. Today it is the largest company in Italy and one of the world's leading integrated oil and gas producers. Its Polish counterpart would be the planned concern combining ORLEN, LOTOS, and ENERGA [87].

The merger of PKN Orlen with PGNiG and Grupa Lotos is a complex project, but, because of it, an entity will be created that will match the potential of the euro with its competitors. As assessed by the participants of the 6th edition of Congress 590, after consolidation, it will have a much greater investment potential and will be able to increase its involvement in low- and zero-emission energy investments [88].

PKN Orlen contributes to the strengthening of the development of capital concentration, which will not burden the natural environment. However, supporting the development of renewable energy sources in the energy sector or alternative fuels in transport requires large investment outlays. This is possible only thanks to building a strong multi-energy concern. Thus, a multi-energy concern has a chance to make a green transformation.

The new entity is a response to the revolutionary challenges faced by the energy market today [89].

Author Contributions: Conceptualization, J.T.-M. and M.W.-J.; Data curation, J.T.-M.; Formal analysis, M.W.-J. and J.T.-M.; Funding acquisition, J.T.-M. and M.W.-J.; Methodology, M.W.-J. and J.T.-M.; Project administration, J.T.-M. and M.W.-J.; Resources, J.T.-M. and M.W.-J.; Software, M.W.-J.; Supervision, J.T.-M. and M.W.-J.; Validation, J.T.-M. and M.W.-J.; Visualization, M.W.-J.; Writing—original draft, J.T.-M. and M.W.-J.; Writing—review and editing, J.T.-M. and M.W.-J. All authors have read and agreed to the published version of the manuscript.

Funding: The publication was financed from the subsidy granted to Cracow University of Economics.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Acknowledgments: The authors thank the anonymous Reviewers and the Editors for their valuable contributions that significantly improved this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Yazdi, S.K.; Beygi, E.G. The dynamic impact of renewable energy consumption and financial development on CO2emissions: For selected African countries. *Energy Sources Part B Econ. Plan. Policy* **2017**, *13*, 13–20. [CrossRef]
2. Işik, C.; Kasımatı, E.; Ongan, S. Analyzing the causalities between economic growth, financial development, international trade, tourism expenditure and/on the CO_2 emissions in Greece. *Energy Sources Part B Econ. Plan. Policy* **2017**, *12*, 665–673. [CrossRef]
3. Menon, P. An Indian story on carbon emission, energy consumption, trade openness, and financial development. *J. Public Aff.* **2019**, *19*, e1953. [CrossRef]
4. Lew, G.; Sadowska, B.; Chudy-Laskowska, K.; Zimon, G.; Wójcik-Jurkiewicz, M. Influence of Photovoltaic Development on Decarbonization of Power Generation—Example of Poland. *Energies* **2021**, *14*, 7819. [CrossRef]
5. Drożdż, W.; Kinelski, G.; Czarnecka, M.; Wójcik-Jurkiewicz, M.; Maroušková, A.; Zych, G. Determinants of Decarbonization—How to Realize Sustainable and Low Carbon Cities? *Energies* **2021**, *14*, 2640. [CrossRef]
6. Wójcik-Jurkiewicz, M.; Czarnecka, M.; Kinelski, G.; Sadowska, B.; Bilińska-Reformat, K. Determinants of Decarbonisation in the Transformation of the Energy Sector: The Case of Poland. *Energies* **2021**, *14*, 1217. [CrossRef]
7. United Nations. Transforming OurWorld: The 2030 Agenda for Sustainable Development. 2015. Available online: www.https://sustainabledevelopment.un.org (accessed on 22 November 2021).
8. United Nations. The Paris Agreement. 2015. Available online: https://unfccc.int/sites/default/files/english_paris_agreement.pdf (accessed on 22 November 2021).
9. United Nations. High-Level Dialogue on Energy 2021. Available online: https://www.un.org/sites/un2.un.org/files/20-01529_att_concept_note_-_hl_dialogue_on_energy_2021.pdf (accessed on 22 November 2021).
10. Camodeca, R.; Almici, A. Digital Transformation and Convergence toward the 2030 Agenda's Sustainability Development Goals: Evidence from Italian Listed Firms. *Sustainability* **2021**, *13*, 11831. [CrossRef]
11. Hall, R.P.; Ranganathan, S.; G. C., R.K. A General Micro-Level Modeling Approach to Analyzing Interconnected SDGs: Achieving SDG 6 and More through Multiple-Use Water Services (MUS). *Sustainability* **2017**, *9*, 314. [CrossRef]
12. Assembly, G. *United Nations: Transforming Our World: The 2030 Agenda for Sustainable Development*; UN: New York, NY, USA, 2015.

13. Toborek-Mazur, J. *Kontrowersje Wokół Rozliczania Fuzji w Międzynarodowych Standardach Rachunkowości*; Luty, Z., Chmielowiec-Lewczuk, M., Eds.; Rachunkowość–polityka makroekonomiczna–globalizacja; Wydawnictwo Uniwersytetu Ekonomicznego we Wrocławiu: Wrocław, Poland, 2015; p. 390.
14. Toborek-Mazur, J. *Transakcje Fuzji i Przejęć Jako Przejaw Globalizacji w Praktyce*; Makowiec, M., Ed.; Wybrane Problemy w kształtowaniu zachowań organizacyjnych; Uniwersytet Ekonomiczny w Krakowie: Kraków, Poland, 2015.
15. Puzio, E. *Uwarunkowania Fuzji i Przejęć Przedsiębiorstw*; Współczesne Problemy Ekonomiczne: Szczecin, Poland, 2018.
16. Toborek-Mazur, J. Fuzja Spółek w Aspekcie Prawnym i Bilansowym, Studia i Materiały Wydziału Zarządzania i Administracji Wyższej Szkoły Pedagogicznej im. *Jana Kochanowskiego w Kielcach* **2015**, *3*, 439–451.
17. Toborek-Mazur, J. *Holding Jako Podmiot Rachunkowości*; Wydawnictwo Wolters Kluwers: Warszawa, Poland, 2010.
18. Toborek-Mazur, J. *Holding w Aspekcie Prawnym, Bilansowym i Podatkowym*; Oficyna Ekonomiczna: Kraków, Poland, 2005.
19. Świetla, K.; Toborek-Mazur, J. Motywy przejęć odwrotnych i zasady ich rozliczania. *Zesz. Teor. Rachun.* **2020**, *108*, 164.
20. Mamcarczyk, M.; Popławski, Ł.; Zieniuk, P. Key Audit Matters in the Auditor's Reports on the Example of European Mining Companies. *Acta Montan. Slovaca* **2020**, *25*, 453–465. [CrossRef]
21. Świetla, K.; Toborek-Mazur, J. Verification of the Accuracy of Mergers and Acquisitions in Poland in 2012–2020. In Proceedings of the 38th IBIMA International Conference, Seville, Spain, 23–24 November 2021; Available online: https://www.ibimapublishing.com (accessed on 9 December 2021).
22. Kozłowska-Makóś, D. Efekt synergii w procesach łączenia się kapitału (wybrane problemy), Zarządzanie finansami i rachunkowość. *J. Financ. Manag. Account.* **2015**, *3*, 2.
23. Raport KPMG Charakterystyka Procesów Transakcyjnych w Polsce. Oczekiwania a Rzeczywistość, KPMG, Warszawa. 2021. Available online: https://assets.kpmg/content/dam/kpmg/pl/pdf/2019/11/pl-Raport-KPMG-Charakterystyka-procesow-transakcyjnych-w-PL.pdf (accessed on 2 February 2022).
24. Polish Transmission System Operator: The New Name of the Company. Available online: https://www.pse.pl/web/pse-eng/news/news/-/asset_publisher/6OMoxwXL8Emh/content/polish-transmission-system-operator-the-new-name-of-the-company?safeargs=696e686572697452656469726563743d66616c7365 (accessed on 2 February 2022).
25. Homberg, F.; Osterloh, M. Fusionenund und Übernahmen im Licht der Hybris–Überblicküber den Forschungsstand. *J. fÜRBetr.* **2010**, *60*, 269–294.
26. Philips, G.M.; Zhdanov, A. R&D and the Incentives from Merger and Acquisition Activity. *Rev. Financ. Stud.* **2013**, *26*, 34–78.
27. Toborek-Mazur, J. *Reverse Acquisition Processes as an Example of Company Financial Result Creation: Theory of Management 7: The Selected Problems for the Development Support of Management Knowledge Base*; Scientific Papers; University of Zilina: Žilina, Slovakia, 2014; pp. 94–96.
28. Toborek-Mazur, J. Wpływ koncepcji konsolidacji sprawozdań finansowych na zmiany w międzynarodowych przepisach dotyczących rachunkowości. *Zesz. Teor. Rachun.* **2014**, *76*, 132.
29. Walsh, J.P. Doing a deal: Merger and acquisition negotiations and their impact upon target company top management turnover. *Strateg. Manag. J.* **1989**, *10*, 307–322. [CrossRef]
30. Freitas, A.R.R.; Napimoga, M.; Donalisio, M.R. Analise da gravidade da pandemia de COVID-19, Artigo de opiniao. *Epidemiol. Serv. Saude* **2020**, *29*, e2020119.
31. Szymczyk, J. Changes in Marketing Strategies in the Fashion Sector Caused by the COVID-19 Pandemic. *Humanit. Univ. Res. Pap. Manag. Spec. Issue* **2020**, *XXI*, 215–229. [CrossRef]
32. Gulińska, A.; Kordala, T. Kontrola koncentracji w Polsce w czasach pandemii koronawirusa i spowodowanego nią kryzysu gospodarczego–podsumowanie praktyki i postulaty de lege ferenda. *Internetowy Kwart. Antymonop. Regul.* **2021**, *1*, 8–27.
33. Helin, A.; Zorde, K.; Bernaziuk, A.; Kowalski, R. *Fuzje i Przejęcia Spółek Kapitałowych. Zagadnienia Rachunkowe i Podatkowe*; Wydawnictwo C.H. Beck: Warszawa, Poland, 2019.
34. Chadam, J. *Synergia i Wartość w Strukturach Kapitałowych*; Difin: Warszawa, Poland, 2012.
35. Korpus, J. *Fuzje i Przejęcia–Czynniki Sukcesu i Przyczyny Niepowodzeń*; Konkurencyjność i Innowacyjność Przedsiębiorstw: Warszawa, Poland, 2011.
36. Kołodko, G.W. *Pandemia: Praktyczne Reakcje i Teoretyczne Pytania, Kwartalnik Nauk o Przedsiębiorstwie 2(55)*; Szkoła Główna Handlowa w Warszawie: Warszawa, Poland, 2020; pp. 5–14.
37. Włodarczyk, B.; Firoiu, D.; Ionescu, G.H.; Ghiocel, F.; Szturo, M.; Markowski, L. Assessing the Sustainable Development and Renewable Energy Sources Relationship in EU Countries. *Energies* **2021**, *14*, 2323. [CrossRef]
38. Czerkas, K. *Przejmowanie Przedsiębiorstw, Zorganizowanych Części Przedsiębiorstw Oraz Nieruchomości. Fuzje Przedsiębiorstw. Aspekty Prawne, Finansowe, Podatkowe i Organizacyjne*; ODDK: Gdańsk, Poland, 2018.
39. Malec, M.; Kinelski, G.; Czarnecka, M. The Impact of COVID-19 on Electricity Demand Profiles: A Case Study of Selected Business Clients in Poland. *Energies* **2021**, *14*, 5332. [CrossRef]
40. Czakon, W.; Mucha-Kuś, K.; Sołtysik, M. Coopetitive Platform: Common Benefits in Electricity and Gas Distribution. *Energies* **2021**, *14*, 7113. [CrossRef]
41. Zimon, G. An assessment of the strategy of working capital management in polish energy companies. *Int. J. Energy Econ. Policy* **2019**, *9*, 552–556. [CrossRef]
42. Pietruszka-Ortyl, A.; Ćwiek, M.; Ziębicki, B.; Wójcik-Karpacz, A. Organizational Culture as a Prerequisite for Knowledge Transfer among IT Professionals: The Case of Energy Companies. *Energies* **2021**, *14*, 8139. [CrossRef]

43. Górowski, I.; Kurek, B.; Szarucki, M. The Impact of a New Accounting Standard on Assets, Liabilities and Leverage of Companies: Evidence from Energy Industry. *Energies* **2022**, *15*, 1293. [CrossRef]
44. Hategan, C.-D.; Pitorac, R.-I.; Milu, N.-D. Assessment of the Mandatory Non-Financial Reporting of Romanian Companies in the Circular Economy Context. *Int. J. Environ. Res. Public Health* **2021**, *18*, 12899. [CrossRef]
45. Zieniuk, P. Disclosures Regarding the Risk of Estimated Measurement in the Financial Statements—Behavioral Aspects. *Zesz. Teor. Rachun.* **2019**, *104*, 171–188. [CrossRef]
46. Copeland, T.; Koller, T.; Murrin, J. *Wycena: Mierzenie i Kształtowanie Wartości Firm*; WIG PRESS: Warszawa, Poland, 1997.
47. Gumułka, J.; Figurski, A. Fuzje i przejęcia jako czynniki stymulujące rozwój przedsiębiorstw na przykładzie spółki Cyfrowy Polsat, S.A. Zesz. Naukowy.Pl/Wyższa Szkoła Zarządzania Bank. *Krakowie* **2015**, *35*, 26–41.
48. Deloitte, Rynek Fuzji i Przejęć a COVID-19. Wyznaczanie Nowych Horyzontów. Available online: https://www2.deloitte.com/pl/pl/pages/finance/articles/rynek-fuzji-przejec-a-covid-19-raport.html (accessed on 23 November 2021).
49. Brigham, E.F.; Gapenski, L.C. *Zarządzanie Finansami, t. 2*; PWE: Warszawa, Poland, 2000.
50. Frąckowiak, W. *Fuzje i Przejęcia Przedsiębiorstw*; Polskie Wydawnictwo Ekonomiczne: Warszawa, Poland, 1998.
51. Goździszewska, A. Fuzje Przedsiębiorstw, Zeszyty Naukowe Uniwersytetu Szczecińskiego nr 640. Finanse, Rynki Finansowe, Ubezpieczenia nr 38, Szczecin 2011, s. 570. Available online: https://wneiz.pl/nauka_wneiz/frfu/38-2011/FRFU-38-569.pdf (accessed on 2 February 2022).
52. Kolegowicz, K.; Szymla, W. Intensywność i Charakter Procesów Internacjonalizacji Przedsiębiorstw Sektora Elektroenergetycznego w Latach 2002–2011. Available online: https://www-arch.polsl.pl/Wydzialy/ROZ/Kwartalnik/Documents/KN20.pdf (accessed on 2 February 2022).
53. Lulek, A.; Lew, G.; Masztalerz, M.; Sadowska, B.; Wójcik-Jurkiewicz, M. The Impact of Chemical Companies on the Environment and Local Communities in the Aspect of Business Model. *Eur. Res. Stud. J.* **2021**, *XXIV*, 548–563. [CrossRef]
54. Law, J. *A Dictionary of Accounting*; Market House Books Ltd.: Oxford, UK, 1999; p. 235.
55. De Pamphilis, D. *Mergers, Acquisitions, and Other Restructuring Activities*; Academic Print of Elsevier: San Diego, CA, USA, 2012.
56. Informacje o Spółce Energa S.A. Available online: https://notowania.pb.pl/instrument/PLENERG00022/energa/informacje-spolka (accessed on 5 November 2021).
57. Struktura Własnościowa CEZ Polska Sp. z o.o. Available online: https://www.cezpolska.pl/pl/cez-w-polsce/grupa-cez/struktura-wlasnosciowa (accessed on 5 November 2021).
58. Raporty M&A Index Polska za Lata 2009–2020, Raporty Branżowe. Available online: https://fordata.pl/category/blog/raporty-branzowe/ (accessed on 2 July 2021).
59. M&A Index Poland.Fuzje i Przejęcia w 2018 Roku. Raport Przygotowany Przez Firmy Navigator Capital oraz FORDATA Grudzień 2018 Roku. Available online: http://www.navigatorcapital.pl/wp-content/uploads/2018/12/Raport_MnAIndexPoland_rok2018_PL.pdf (accessed on 22 November 2021).
60. Raport Sektorowy—Energetyka. Available online: https://profit-journal.pl/raport-sektorowy-energetyka (accessed on 2 February 2022).
61. Sektor Energetyczny w Polsce, Polska Agencja Informacji i Inwestycji Zagranicznych S.A. Available online: https://www.paih.gov.pl/files/?id_plik=19609 (accessed on 22 November 2021).
62. ARE. Available online: https://www.rynekelektryczny.pl/moc-zainstalowana-oze-w-polsce/ (accessed on 1 December 2021).
63. Przejęcie Kapitałowe Grupy ENERGA Przez PKN ORLEN da Impuls do Dalszego Rozwoju. Available online: https://www.orlen.pl/PL/BiuroPrasowe/Strony/Przej%C4%99cie-kapita%C5%82owe-Grupy-ENERGA-przez-PKN-ORLEN-da-impuls-do-dalszego-rozwoju.aspx (accessed on 15 October 2021).
64. Połączenie PKN ORLEN i Grupy Energa. Available online: https://www.kierunekchemia.pl/artykul,74849,przejecie-kapitalowe-grupy-energa-przez-pkn-orlen-da-impuls-do-dalszego-rozwoju.html (accessed on 22 November 2021).
65. Jednostkowe Wyniki Finansowe za 2019 rok Energa S.A. Available online: https://ir.energa.pl/pr/518450/jednostkowe-wyniki-finansowe-za-2019-rok (accessed on 19 September 2021).
66. Dane finansowe Energa S.A. Available online: https://ir.energa.pl/pl/ir/serwis-relacji-inwestorskich/dane-finansowe/Dane-finansowe (accessed on 19 August 2021).
67. Currently Losses Amount to at Least PLN 1.3 Billion. Available online: https://businessinsider.com.pl/finanse/miliardowe-straty-w-elektrowni-ostroleka-podajemy-zarobki-menedzerow/khdxrk (accessed on 19 August 2021).
68. Available online: https://www.orlen.pl/PL/BiuroPrasowe/Strony/PKN-ORLEN-sfinalizowa%C5%82-przej%C4%99cie-Grupy-ENERGA.aspx (accessed on 25 August 2021).
69. MSR36 "Utrata Wartości Aktywów", Seria Nowe Standardy Sprawozdawczości, Oficyna Finansowo–Księgowa. Available online: https://oficynafk.pl/237/msr-36-utrata-wartosci-aktywow-17294.html (accessed on 2 July 2021).
70. Skonsolidowany Raport Roczny Grupy Kapitałowej Tauron Polska Polska Energia za 2015 r. Available online: https://www.tauron.pl/-/media/offer-documents/tauron/raporty-okresowe/2015/raporty-roczne-za-2015/tauron_skonsolidowany_raport_roczny_2015.ashx (accessed on 22 November 2021).
71. Skonsolidowany Raport Roczny Grupy Kapitałowej Tauron Polska Polska Energia za 2018 r. Available online: https://www.tauron.pl/-/media/offer-documents/tauron/raporty-okresowe/2018/roczne-2018/skonsolidowany-raport-roczny-grupy-kapitaowej-tauron-polska-energia-sa-za-2018-r.ashx (accessed on 22 November 2021).

72. Skonsolidowany Raport Roczny Grupy Kapitałowej Tauron Polska Polska Energia za 2019 r. Available online: https://www.tauron.pl/-/media/offer-documents/tauron/raporty-okresowe/2019/roczny/skonsolidowany_raport_roczny_za-2019_r.ashx (accessed on 22 November 2021).
73. Grupa Kapitałowa TAURON Polska Energia S.A. Skonsolidowane Sprawozdanie z Płatności na Rzecz Administracji Publicznej za rok zakończony Dnia 31 Grudnia 2020 Roku. Available online: https://raportzintegrowany2020.orlen.pl/uploads/CENTRUM_DOKUMENTOW/3_Skonsolidowane_sprawozdanie_z_p%C5%82atnosci_na_rzecz_administracji_publicznej_2020.pdf (accessed on 22 November 2021).
74. Available online: https://biznesalert.pl/raport-pakiet-klimatyczny-fot-for-55-prawo-klimatyczne-oze-energetyka/ (accessed on 22 October 2021).
75. Available online: https://businessinsider.com.pl/finanse/miliardowe-straty-w-elektrowni-ostroleka-podajemy-zarobki-menedzerow/khdxrk5 (accessed on 22 November 2021).
76. Bouwens, J.; de Kok, T.; Verriest, A. The prevalence and validity of EBITDA as a performance measure. *Account. Audit. Control* **2019**, *25*, 55–105. [CrossRef]
77. Available online: http://globenergia.pl/sklep/product/wydanie-globenergia-4-2020/ (accessed on 22 November 2021).
78. Available online: https://www.gov.pl/web/aktywa-panstwowe/spolki-skarbu-panstwa-razem-na-drodze-do-transformacji-sektora-elektroenergetycznego (accessed on 2 October 2021).
79. Available online: https://media.Tauron.pl/pr/199358/Tauron-zostal-podatkowa-grupa-kapitalowa (accessed on 2 October 2021).
80. Available online: https://www.money.pl/gielda/przejecie-pgnig-i-lotos-orlen-zdradzil-szczegoly-podpisanej-umowy-o-wspolpracy-6638812554394432a.html (accessed on 2 October 2021).
81. Available online: https://stat.gov.pl/Klasyfikacje/doc/pkd_07/pkd_07.html (accessed on 22 October 2021).
82. Available online: https://wysokienapiecie.pl/24792-orlen-chce-przejac-energe/ (accessed on 22 October 2021).
83. Available online: https://www.pap.pl/centrum-prasowe/687170%2Cduzy-moze-wiecej-konsolidacja-rynku-sposobem-na-bezpieczenstwo-paliwowo (accessed on 22 October 2021).
84. Available online: https://www.rp.pl/Najwazniejsze-firmy/305219853-Wielka-czworka-branzy-energetycznej.html (accessed on 22 October 2021).
85. Available online: https://www.wnp.pl/energetyka/tauron-chce-odkupic-od-pfr-udzialy-w-spolce-nowe-jaworzno,489401.html (accessed on 18 September 2021).
86. Available online: https://www.kierunekenergetyka.pl/artykul,37029,niemal-330-mld-euro-w-sektorze-elektroenergetycznym-rekordowa-wartosc-fuzji-i-przejec-w-2016-roku.html (accessed on 2 February 2022).
87. Available online: https://www2.deloitte.com/pl/pl/pages/finance/articles/top-500-w-branzy-energetycznej-i-surowcowej.html (accessed on 2 February 2022).
88. Available online: https://kongres590.pl/ (accessed on 2 February 2022).
89. Available online: https://www.cire.pl/artykuly/opinie/95866-dlaczego-taniej-oznacza-drozej-skutki-monopolizacji-rynku-energii-i-erozji-systemu-wsparcia-oze (accessed on 2 February 2022).

energies

Article

The Business Model in Energy Sector Reporting—A Case Study from Poland: A Pilot Study

Beata Sadowska [1], Magdalena Wójcik-Jurkiewicz [2,*], Grzegorz Zimon [3,*], Adam Lulek [1], Nina Stępnicka [4] and Robert Walasek [5]

1 Department of Accounting, Faculty of Economics, Finance and Management, University of Szczecin, 70-453 Szczecin, Poland
2 Department of Accounting, Institute of Management, College of Management Sciences and Quality, Cracow University of Economics, 31-510 Krakow, Poland
3 Department of Finance, Banking and Accountancy, Faculty of Management, Rzeszow University of Technology, 35-959 Rzeszow, Poland
4 Faculty of Law and Social Sciences, Jan Kochanowski University in Kielce, 25-369 Kielce, Poland
5 Faculty of Management, Department of Logistics, University of Lodz, 90-237 Lodz, Poland
* Correspondence: magdalena.wojcik-jurkiewicz@uek.krakow.pl (M.W.-J.); gzimon@prz.edu.pl (G.Z.)

Abstract: The business model is understood as a way of generating revenue and creating value. This article aimed to define the framework and detailed characteristics of the business model in corporate reporting in the energy sector. The study also addressed the issue of value creation and examined the correlation between reporting information about the business model and the value of the enterprise, calculated using selected accounting measures. The research was conducted in 2021 on all listed companies in the energy sector included in the WIG20 index in 2019–2020. The research methodologies included critical analysis of the literature, analysis of the content of corporate publications, comparative analysis, analysis of phenomena and synthesis of results, Spearman's rank correlations, and graphical data presentation. The originality of our research concerns directing attention to the disclosure and reporting of information about the business model in corporate reports in the energy sector in Poland. This is the first such study in Poland conducted on companies in the energy sector; therefore, it is treated by the authors as a pilot study. The results show that companies in the energy sector included in the WIG20 index do not disclose information about their business models in reports and the structure of published reports is very diverse, which makes it even more difficult to compare financial and non-financial data. Enterprises in the energy sector disclose financial and non-financial information in financial statements and the reports of the management board on the activities of the company and the capital group. The financial information disclosed by the companies most often included financial and productive capital. Energy companies are reluctant to disclose information about by-products and waste.

Keywords: business model; integrated reporting; non-financial reporting; energy sector; Warsaw Stock Exchange (WSE)

Citation: Sadowska, B.; Wójcik-Jurkiewicz, M.; Zimon, G.; Lulek, A.; Stępnicka, N.; Walasek, R. The Business Model in Energy Sector Reporting—A Case Study from Poland: A Pilot Study. *Energies* **2023**, *16*, 1955. https://doi.org/10.3390/en16041955

Academic Editor: Krushna Mahapatra

Received: 8 January 2023
Revised: 9 February 2023
Accepted: 13 February 2023
Published: 16 February 2023

1. Introduction

In the past decade, there has been a huge amount of research related to the business model in terms of both management and accounting [1,2]. Especially in the last twenty years, the business model has become a popular topic in research and practice [1–3]. Many articles discuss the theoretical and practical aspects of creating a company's business product in the context of increasing competition around the world [4–6]. Various aspects have been analyzed, for example, the impact of the company's openness to stakeholders on the effectiveness of the company's business model [7], the business model in agricultural enterprises [8], the relationship between knowledge orientation and business analytics capabilities in driving business [9], integrated management of multiple business models, and the strategic management of business model innovation [10].

This fact means that research on the business model has not been established based on economic research or management. The ambiguity of placing the business model in scientific research leads to a differentiated assessment of its usefulness and value creation architecture [11]. The business model is one of the most commonly used terms in strategic management and, more recently, in accounting [12–14]. Although the term was initially used in the context of e-commerce, its application is currently comprehensive and includes research in many sectors, such as energy, manufacturing, healthcare, and biotechnology [15–19]. The use of the business model concept has increased as researchers studying strategic management and the development of modern business forms, such as business groups, have begun to take an interest [20–23]. Integrated reporting is often combined with the concept of integrated thinking [24] in the context of creating a sustainable business model [25–29]. This is especially important for companies that have a significant impact on the environment, such as transport companies or energy operators. Each individual company, depending on its proximity and distance to impact on the environment, formulates its strategy, vision and mission, accounting policy, and business model. The energy sector is not isolated in the implementation of these activities. Entrepreneurs conducting business activity in the field of logistics services represent the group with the fastest reaction to changes taking place in the market, thus defining their own business model. In the case of enterprises in the energy sector, the business models are a combination of strategic orientation and technology, which is an essential element of achieving business goals and generating positive results from operations [30,31]. However, there is a noticeable gap in the research concerning integrated reporting on applied business models in this sector. A few studies have explored the value creation process of the low-cost carrier business model in the aerospace industry [32–34]. Another case study refers to research on the development of the sustainability habitus in the Arab Middle East (ME) using the example of a leader in the energy sector. In these studies, a comparative analysis of integrated reporting and environmental reporting was performed [35]. Ciubotariu et al. [36] suggested that based on sensitivity function value, sectors of activity such as transport, infrastructure, services, and trade have a higher sensitivity preference for IR (integrated reporting) due to quantification of the stakeholders' interest in terms of performance-positive trend indexes.

In our research, we adopted the theoretical framework of the business model in terms of corporate accounting and financial reporting and related it to enterprises in the energy sector in Poland [37–40]. On 9 December 2013, the International Integrated Reporting Council (IIRC) released the first internationally recognized IR framework. IR is understood as "a process founded on integrated thinking that results in a periodic integrated report by an organization about value creation over time and related communications regarding aspects of value creation" [41]. In the literature, several theoretical papers explain why disclosing the business model could be useful in allowing investors to predict future earnings and cash flow [42–46]. Moreover, the business model is one of the most important elements in the strategy of communication between enterprises and current and potential investors. There are many approaches to the category of "business model," among which is a link between economic theory and accounting valuation and thus with financial and non-financial reporting [18]. From a business model perspective, it is acknowledged that any asset can be utilized in different ways and that value creation, another concept key to IR, will ultimately vary between firms. The challenge at hand is the alignment of the financial perspective with the value proposition of the enterprise [14,32].

This paper contributes to the accounting literature as it provides evidence that the voluntary disclosure of macro components encounters many limitations related to the communication of the activities of the enterprise, especially in the case of environmental impact [47]. This was confirmed by research conducted in Russia on enterprises in the transport sector, which proved that there was a lack of transparency in communicating the activities and business models of these enterprises [48–51]. Our results are of interest not only to researchers but also to practitioners and standard setters. In particular, they highlight the importance of disclosing information concerning business models related to this sector in Poland in order to improve the usefulness of accounting [52–56].

Our research aimed to define the framework and detailed characteristics of the business model in corporate reporting in the energy sector. Our research was conducted on a sample of listed companies in the energy sector included in the WIG20 index for the years 2019–2020. We used disclosure maps proposed by CIMA and IIRC [32], which allowed us to conduct a detailed analysis of disclosures regarding the business models used.

The business model describes how ways of creating and delivering value can evolve as customer needs and preferences change [57]. It is a structure that provides information about the enterprise's prospects. It can be assumed that the business model describes what the company offers to its customers, how it reaches them with the offer, how it maintains relations with them, what resources it engages, what actions it takes for this purpose, with whom it enters into a partnership and, consequently, how it achieves revenues [58–60].

Progressive changes, including the deregulation of markets, development of technology, provision of services, flow of information and communication, and coordination of markets and economies make the business model increasingly necessary for enterprises to achieve market success and a sustainable competitive advantage. It is a determinant of creating the value of an individual enterprise [61]. The value category can be considered from a broad perspective, both financial and non-financial. The key in the process of creating a business model by enterprises in the energy sector appears to be understanding the essence of this concept and the correct selection of components. It should be noted that it is difficult and rather impossible to clearly define the business model [62,63] as the definitions are numerous and include diverse elements.

This paper proceeds as follows. The "Related Literature" section reviews the literature on the topic investigated and describes our research hypotheses. The "Materials and Methods" section provides details about our sample selection strategy and research design. The "Results" section presents our research results, while the "Discussion" and "Conclusions" sections contain a discussion of the implications, limitations, and possible future developments of the research.

2. Related Literature

The topic of the business model has attracted the attention of researchers since the 1990s, which is primarily related to the development of new information and communication technologies and the phenomenon of globalization [61–66]. The essence of the business model is to explain how organizations create, deliver, and capture value [67–71]. The business model is perceived as a key factor for creating and maintaining a competitive advantage as well as achieving corporate financial results. Business models evolve as managers both introduce new ideas and adjust in response to external factors [1–3]. As research shows, it can also communicate the business logic of the enterprise to a wide group, such as shareholders [45]. This unique ability of the business model to communicate value has resulted in the fact that various accounting organizations [20,51–54] currently perceive it in terms of increasing the transparency and clarity of financial disclosures. Despite its undeniable advantages, the concept of the business model also has several important gaps, both cognitive and technical [55]. The cognitive gap refers to the lack of agreement on the unambiguous understanding of the term business model, which is the reason for the frequent development of a specific understanding of this term dependent on the academic center formulating it. In turn, the technical gap is generally expressed by the lack of guidance in the presentation of information within the business model. At the same time, the business model considered from the point of view of the economic theory of the company provides practical difficulties in the area of financial reporting measurement [72,73]. Sustainable business models strive to balance economic prosperity, social well-being, and environmental preservation in their operations and strategies [73].

In our article, based on the concept of a business model in corporate reporting, we have formulated the following research hypotheses:

Hypothesis 1 (H1). ***Do companies in the energy sector use the business model concept in their reports?***

Hypothesis 2 (H2). *How are business model disclosures identified in corporate reports in the energy sector?*

Hypothesis 3 (H3). *Is the structure of the reports published by companies in the energy sector homogeneous or diversified, and do these reports allow for easy comparison of financial and non-financial data?*

Hypothesis 4 (H4). *Do companies in the energy sector have specificities compared to other sectors?*

Hypothesis 5 (H5). *Are there strong correlations between the disclosure of a business model's information and the entity's value?*

In the IIRC framework structure, the term "business model" is defined as "a selected system composed of inputs, business activities, outputs, and outcomes, designed to create a specific value in the short, medium and long term" [50,68]. Reporting and disclosure in corporate reporting should answer the following question: What is the business model of a given organization and to what extent is it sustainable? The components, categories, and detailed characteristics of the business models are presented in Table 1.

Table 1. Components, categories, and detailed characteristics of the business models.

Business Model Categories	Business Model Subcategories	Detailed Characteristics of Business Model Components
Input elements	Financial capital Productive capital Intellectual capital Human capital Natural capital Social capital	Financing model Infrastructure Intellectual property (knowledge, brands, patents) People (training, motivation) Raw materials Relationships
Activity	Business activities	Research and development Planning and design Production and diversification of products Maintenance services Quality control Relationship management Maintenance services
	Output elements	Products Services Waste By-products
Outcome	Financial capital Productive capital Intellectual capital Human capital Natural capital Social capital	Profits/losses, return to shareholder Asset consumption Effects of research and development Creation of employment, employee development Environmental impact Customer satisfaction Philanthropy

Source: Ref. [18], pp. 189–202.

The benefits of integrated reporting apply to many groups interested in creating corporate value, not only financial capital providers. It is proven that integrated reporting combines financial and non-financial reporting processes, paving the way for the transformation of the internal reporting system [74–78]. The process of creating corporate value depends to a large extent on the adopted business model understood as a "system of transforming inputs, through its business activities, into outputs and outcomes" [62]. Enterprises in the energy sector conduct business activities based on diverse business models [79]. The business model is a method of doing business that ensures further operation for the entity. It enables communication with stakeholders, which contributes to reflecting the true value of the company. The lack of complete information (e.g., non-financial) in an integrated report on the business model may lead to a distortion (underestimation) of the value of the economic entity. Enterprise value is also created through communication about the business model.

The business model is a method adopted by the company to increase and use resources, which is presented to customers with an offer of products and services; it is a conceptual tool containing elements and relationships between them. The business model describes how ways of creating and delivering value can evolve as customer needs and preferences change. An unambiguous definition of the business model is difficult and rather impossible because there are many concepts defining the business model, thus it is understood differently by economic units. The business model is often reported in an integrated report.

The business model should inform about the use of the resources by the enterprise in business activities, whereas the key elements of the business model include segments of stakeholders, business partners, customers, value propositions, customer communication channels, stakeholder relations, revenue streams, key resources, key success factors, key partnerships, and cost structure. The business model is built based on these assets shaping the so-called value dynamics. The business model is multidimensional; it is a unique combination of tangible and intangible assets aimed at maximizing the value of the organization.

A key issue, especially for enterprises in the energy sector, is non-financial reporting related to areas such as corporate social responsibility and environmental impact. This issue concerns the transparency of non-financial reporting [80–84]. As evidenced by previous research in Poland, the lack of compulsory environmental disclosure has discouraged managers from voluntarily disclosing such information [82–86]. However, the current discourse on business models highlights an increase in levels of disclosure of both financial and non-financial information [87–90]. In particular, relating non-financial reporting to value in the long term is problematic, taking into account intangible values that are not measured or communicated [90,91].

Communicating information about the business model and non-financial capital should be the next stage in the evolution of the company's reporting and this type of disclosure should be carried out in a specific reporting format, called the integrated report [91,92]. However, there is currently a turbulent scientific discourse about the essence of understanding the business model, in terms of referring it to management paradigms, embedding it in the criterion of environmental impact, as well as cause-and-effect relationships and correlations between other ontological entities. The ambiguity of the definitions and the multiplicity of elements forming the business model structure stem, on the one hand, from the variability of the realities of running a business and their perception by decision-makers, and, on the other hand, from the evolution of concepts and theories explaining these processes and phenomena.

3. Materials and Methods

In our research, we used financial statements and reports of companies from the energy sector listed on the Warsaw Stock Exchange (WSE). There are seven listed companies on the WSE. Table 2 presents the surveyed companies and additionally indicates the industries of each of the companies in the energy sector and the detailed scope of their activities.

The leading activity of the studied companies was transport. The companies conducted diversified business activities related to the domestic market. Table 1 also indicates the business model disclosures analyzed in the reports.

Table 2. List of companies and reports in which financial and non-financial information was disclosed.

Enterprise/Company	Report
ELEKTROCIEPŁOWNIA BĘDZIN SPÓŁKA AKCYJNA (BDZ)	- Consolidated financial statements; - Report of the management board on the company's activities
ENEA SPÓŁKA AKCYJNA (ENA)	- No published reports for 2019 and 2020; - Last consolidated financial statements were published for 2016
ENERGA SPÓŁKA AKCYJNA (ENG)	- Report on non-financial information of the capital group
PGE POLSKA GRUPA ENERGETYCZNA SPÓŁKA AKCYJNA (PGE)	- Integrated report
POLENERGIA SPÓŁKA AKCYJNA (PEP)	- Consolidated financial statements; - Report of the management board on the company's activities
TAURON POLSKA ENERGIA SPÓŁKA AKCYJNA (TPE)	- Consolidated financial statements; - Report of the management board on the company's activities
ZE PAK SPÓŁKA AKCYJNA (ZEP)	- No published reports for 2019 and 2020

Source: Study based on our own research.

The survey was conducted in 2021 based on financial and non-financial data available for 2019–2020. The layout and content of the study were subordinated to the implementation of the assumed purpose of the study. The authors used a pilot testing method and combined it with other methods, such as experiments and observational studies, to provide a more comprehensive understanding of the research questions. As a research method, we empirically analyzed the material, which allowed us to verify the research hypotheses posed. The methodology process involved several steps. The first step included a selection and review of the literature. This included identifying texts that were relevant to the research question or topic being studied. The authors also organized articles and identify patterns and connections between them. The next step was to combine the information from the texts to create a comprehensive understanding of the topic or research question. Finally, conclusions and interpretations were drawn.

This research approach is widely accepted in studies exploring capital information disclosures in business models [26]. It should be emphasized that the small research sample was conditioned by the small number of enterprises that currently publish comprehensive information about their business model. The business model disclosures were drawn from various reports as there is no single unified concept of business model reporting. We did not have comparable and extensive research on business model disclosures by the industry. Sometimes, the disclosures were fragmented, incomplete, and impossible to compare.

The study also addressed the issue of value creation and examined the correlation between reporting information about the business model and the value of the enterprise, which was calculated using selected accounting measures. As part of the current study, the interdependencies of the detailed components of the business model were examined—i.e., the correlation relationships that occurred between the sum of disclosures about the business model in selected components for the surveyed enterprises and the value of the enterprise, measured using selected accounting methods, achieved by these entities. These included total assets, financial results, and equity. Statistical analysis of the correlations was carried out based on the Spearman correlation method, i.e., coefficients were calculated for the ranks of variables. The argument for using this statistical method was the small size of the group; as this was a preliminary, pilot study that will be continued on a large group of entities this year. As an additional argument for choosing this statistical method, we also considered the fact that the correlation coefficients calculated for the ranks of variables showed any monotonic relationship, and the distribution of the research sample was not linear.

Among the surveyed companies, there were no significant differences in the structures of the reports in which the information about the business models was disclosed. Two of the seven companies in the energy sector listed on the Warsaw Stock Exchange had not published current financial statements or non-financial reports for the years 2019–2020. One company, COM4, drew up an integrated report, while another one, COM3, reported the non-financial information of the capital group, and three companies disclosed information about the results of their activities in the consolidated financial statements and in the management board's report on the activities of the company and the capital group (Table 3).

Table 3. The number of disclosures on components of the business model of companies in the energy sector.

	Input Elements		Input Elements -Only Financial		Business Activities		Business Activities-Only Financial		Output Results		Output Results-Only Financial Information		Outcomes		Outcomes-Only Financial Information		Total	
	2019	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
BDZ	1	1	1	1	1	1	1	1	1	1	1	1	4	4	2	2	12	12
ENA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ENG	6	0	3	0	5	0	2	0	1	0	1	0	4	0	2	0	24	0
PGE	6	0	3	0	6	0	3	0	4	0	2	0	4	0	2	0	30	0
PEP	2	2	1	1	3	3	2	2	1	1	1	1	2	2	1	1	13	13
TPE	4	4	2	2	2	1	2	1	1	1	1	1	2	2	1	1	17	15
ZEP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOT	19	7	10	4	17	5	10	4	8	3	6	3	16	8	8	4	96	40

Source: Study based on our own research.

The study of the number of disclosures indicated that logistics companies most often report information about the input elements (capital), including mainly financial elements and business outcomes, both financial and non-financial. Slightly less often, enterprises disclose information about business activities (most commonly about planning, design, and risk). Some components of the business model were not disclosed in single cases—no data were reported in the period under review. A characteristic situation for the entire research sample was that the information highlighted in the components of the business model was at a similar level in 2019 and 2020. This was reflected in the score of the individual components (Table 4).

In the next stage of the study, detailed elements of the components of the business model and information regarding financial (numerical) disclosures were subjected to in-depth content analysis for all surveyed logistics companies (Table 4). It should be noted that the empirical data confirmed the dominant verbal nature of disclosures about the business model. There was a much greater number of financial (numerical) information disclosures in the surveyed logistics companies than those of a descriptive nature. The largest percentage of financial disclosures among the total information was recorded for the business activities component in 2019 (i.e., 74%), whereas the smallest percentage of financial disclosures was recorded for the business activities component in 2020 (i.e., 27%).

Table 4. The number of disclosures on components of the business model of companies in the energy sector—only financial information.

Disclosures	2019			2020		
	Total	Only Financial Information		Total	Only Financial Information	
		Number	% of Total Disclosures		Number	% of Total Disclosures
Input Elements						
Financial capital	8	5	62.5	8	3	37.5
Productive capital	6	4	66.6	6	2	33.4
Intellectual capital	4	3	75	4	1	25
Human capital	4	3	75	4	1	25
Natural capital	2	2	100	2	0	0
Social and relational capital	2	2	100	2	0	0
Total input elements	26	19	73	26	7	27
Business Activities						
Planning and design	5	3	60	5	2	40
Risk	8	5	62.5	8	3	37.5
Training	2	2	100	2	0	0
Research and development	2	2	100	2	0	0
Relationship management	2	2	100	2	0	0
Diversification of services	4	3	75	4	1	25
Total business activities	23	17	74	23	6	26
Output Elements						
Products	1	1	100	1	0	0
Services	8	5	62.5	8	3	37.5
Waste	1	1	100	1	0	0
By-products	1	1	100	1	0	0
Total output elements	11	8	73	11	3	27
Outcomes						
Profit/Loss	8	5	62.5	8	3	37.5
Asset consumption	6	3	50	6	3	50
Effects of research and development	2	1	50	2	1	50
Employee development and employment creation	4	3	75	4	1	25
Environmental impact	2	2	100	2	0	0
Customer satisfaction	2	2	100	2	0	0
Total outcomes	24	16	67	24	8	33

Source: Study based on our own research.

4. Results

In our research, we first collected the disclosures reported by logistics companies under four main components of the business model. For this purpose, the disclosure map proposed by CIMA and IIRC was used, according to which the business model consists of 4 components:

1. Input elements, i.e., financial, productive, human, intellectual, natural, social, and relational capitals.
2. Business activities, including planning, design, production, training, research and development, innovation, and relationship management.
3. Outputs and results, including key products, key services, by-products, and waste.
4. Outcomes, including customer satisfaction, profit/loss, return to shareholders, asset consumption, employment creation, employee development and engagement,

improvement of living standards, environmental impact, licenses/certificates, and contribution to the local economy.

Within the indicated components of the business model, 22 types of disclosures were listed, which formed the basis for further analysis. The subject of the study included their descriptive form and disclosures expressed in a monetary measure. The analyses were carried out based on a study of the content of financial statements and reports available on the website of the Warsaw Stock Exchange.

The content analysis was primarily qualitative. Content analysis is defined as a research technique that allows obtaining reproducible and correct conclusions from texts in the context of their use. Its capabilities also concern the use of the quality index as a basis for searching for evidence that the item is or is not disclosed. Detailed results of the analyses are presented in Tables 3–6. For each of the selected parameters describing the business model, the following score was awarded: 1—when such information was disclosed by companies, 0—when there were no disclosures. As a result, the maximum number of points that a given company could be awarded was 22 for one year. In total, it was therefore possible for a company to obtain a maximum of 44 points for both analyzed years. Table 5 presents the results of analyses concerning the input elements, i.e., the capital of the business models of enterprises in the energy sector for the years 2019–2020.

Table 5. Input elements—the capital of the business models of enterprises in the energy sector for the years 2019–2020.

	Capital											
	Financial Capital		Production Capital		Intellectual Capital		Human Capital		Natural Capital		Social and Relational Capital	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
BDZ	1	1	0	0	0	0	0	0	0	0	0	0
ENA	0	0	0	0	0	0	0	0	0	0	0	0
ENG	1	0	1	0	1	0	1	0	1	0	1	0
PGE	1	0	1	0	1	0	1	0	1	0	1	0
PEP	1	1	1	1	0	0	0	0	0	0	0	0
TPE	1	1	1	1	1	1	1	1	0	0	0	0
ZEP	0	0	0	0	0	0	0	0	0	0	0	0

Source: Study based on our own research.

Table 6. Business activities.

	Business Activities											
	Planning and Design		Risk		Training		Research and Development		Relationship Management		Diversification of Services	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
BDZ	0	0	1	1	0	0	0	0	0	0	0	0
ENA	0	0	0	0	0	0	0	0	0	0	0	0
ENG	0	0	1	0	1	0	1	0	1	0	1	0
PGE	1	0	1	0	1	0	1	0	1	0	1	0
PEP	1	1	1	1	0	0	0	0	0	0	1	1
TPE	1	1	1	1	0	0	0	0	0	0	0	0
ZEP	0	0	0	0	0	0	0	0	0	0	0	0

Source: Study based on our own research.

When analyzing capital reporting among the seven companies surveyed, two did not include such information at all, as they did not publish any reports. One of the companies only disclosed information about their financial capital, whereas two companies disclosed information about all of their capital, but only for 2019. They had not yet published reports for 2020. One of the companies disclosed information about financial and productive capital and one enterprise disclosed information about all capital except data on natural and social capital.

In the area of reporting on business activities, companies made various disclosures, as shown in Table 6.

Two companies reported data for both years studied, while the other two had not yet published reports for 2020. Planning and production activities in a descriptive dimension were disclosed by two companies in both years and by one company in 2019. Risk was described by three companies over a period of two years and by two companies in 2019. Information about training, corporate research and development, and relationship management were included in the reports of only two companies in the energy sector and only in 2019. Diversification of services was reported by three companies, two of which disclosed information for 2019.

The output elements of the energy sector enterprises in the business models were also subject to significant variation, as shown in Table 7.

Table 7. Output elements of enterprises in the energy sector for 2019–2020.

	Output Elements							
	Products		Services		Waste		By-Products	
	2019	2020	2019	2020	2019	2020	2019	2020
BDZ	0	0	1	1	0	0	0	0
ENA	0	0	0	0	0	0	0	0
ENG	0	0	1	0	0	0	0	0
PGE	1	0	1	0	1	0	1	0
PEP	0	0	1	1	0	0	0	0
TPE	0	0	1	1	0	0	0	0
ZEP	0	0	0	0	0	0	0	0

Source: Study based on our own research.

It is clear that companies in the energy sector are reluctant to disclose information about by-products, both in financial and descriptive terms. Disclosure of information about waste was at a similar level. Only one company disclosed such information. It can be presumed that in the case of typical service activities, such as logistics activities, these two categories were of negligible importance in the activities of these enterprises. However, the detailed scope of the activities carried out by some companies indicated that production activities or other service activities may have generated waste and by-products in some cases. This requires additional extended research.

Table 8 presents the output outcomes—the capital of the business models of enterprises in the energy sector for the years 2019–2020.

Table 8. Outcomes—the capital of the business models of enterprises in the energy sector for the years 2019–2020.

	Capital: Financial, Productive, Intellectual, Human, Natural, Social											
	Outcomes											
	Profit/Loss		Asset Consumption		Effects of Research and Development		Employee Development and Employment Creation		Environmental Impact		Customer Satisfaction	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
BDZ	1	1	1	1	1	1	1	1	0	0	0	0
ENA	0	0	0	0	0	0	0	0	0	0	0	0
ENG	1	0	0	0	0	0	1	0	1	0	1	0
PGE	1	0	0	0	0	0	1	0	1	0	1	0
PEP	1	1	1	1	0	0	0	0	0	0	0	0
TPE	1	1	1	1	0	0	0	0	0	0	0	0
ZEP	0	0	0	0	0	0	0	0	0	0	0	0

Source: Study based on our own research.

Of the five companies that published their reports, all of them disclosed information about the profit they achieved in 2019. There were no data reported for the two companies in 2020. Asset consumption was reported by three companies during the period under review, and the result of corporate research and development was only reported for one company. Information about employee development and employment creation was published by one energy sector enterprise in both years surveyed, while two companies disclosed these data for 2019. With regard to the information about the impact of the company's activities on the natural environment and the level of customer satisfaction, such information was reported by only two companies in 2019.

It is recommended that the current status of the surveyed WIG20 index companies be reviewed, and integrated reporting should be implemented to disclose, in addition to financial information, non-financial information about corporate social responsibility. The results of the current study confirmed that the surveyed companies included in the WIG 20 index do not disclose information about their business model in annual statements/reports, and disclosures about the business model have a significant role in the value of the enterprise. This was confirmed in research conducted by Kannenberg and Schreck [46] and Jensen and Berg [47].

It is recommended that further research be conducted in this area and new hypotheses are put forward. For example, it should be explored whether larger enterprises, more developed entities with a stronger market position in which the size is scaled with the sum of their assets, use new tools for financial and non-financial reporting on the business model. It is worth continuing research into how small and medium-sized enterprises react and whether they see the need for change. Further research is necessary due to the development of integration of enterprise management systems with accounting systems. This provides new challenges for accountants and controllers and will determine the development of the accounting profession as it evolves into a creative profession.

5. Discussion

In conclusion, it should be noted that in the case of companies in the energy sector, there is no positive approach to reporting on the business model, including non-financial reporting. There is also a significant reduction in the narrative, which could have a negative connotation. Companies disclose mainly financial information in consolidated financial statements and corporate information in the management board's report on activities. In these documents, non-financial information about the business model is limited, practically non-existent, a fact confirmed by our research (Hypothesis 1). Companies should use business models to explain how they generate revenue, create value for their customers, and plan to sustain their competitive advantage. The business model concept is also useful for energy companies to communicate their strategies to stakeholders, such as investors and regulators [47].

As part of the current research, interrelationships between the detailed components of the business model were also examined for the years 2019–2020—i.e., correlations between the sum of disclosures about selected components of the enterprise's business model and the value of the enterprise, measured using selected accounting methods. These include total assets, financial results, and equity. Statistical analysis of the correlations was carried out based on the Spearman correlation method, i.e., coefficients were calculated for the ranks of the variables. The argument for using this statistical method was the small size of the group. The results of the dependence are presented in Tables 9 and 10.

Table 9 shows Spearman's rank correlations for the sum of disclosures of the specified components of the business models of the surveyed enterprises with the selected accounting methods of measuring value.

Table 9. Spearman's rank correlations for all disclosures.

Disclosure	Total Assets (PLN)		Financial Result		Equity Capital	
	2019	2020	2019	2020	2019	2020
Elements at the input	0.5857 (0.2219)	−0.5429 (0.2657)	−0.8714 (0.0237)	−0.0286 (0.9572)	0.3000 (0.5635)	−0.2000 (0.7040)
Business activities	0.7143 (0.1108)	−0.3286 (0.5249)	−0.7143 (0.1108)	0.1857 (0.7246)	0.6000 (0.2080)	0.1286 (0.8082)
Output effects	0.7143 (0.1108)	−0.3143 (0.5441)	−0.2857 (0.5831)	0.2000 (0.7040)	0.5571 (0.2508)	0.0429 (0.9358)
Results	0.8429 (0.0351)	−0.2429 (0.6429)	−0.3571 (0.4871)	0.2714 (0.6029)	0.5571 (0.2508)	0.0429 (0.9358)
Total	0.6000 (0.2080)	−0.5429 (0.2657)	−0.8286 (0.0416)	−0.0286 (0.9572)	0.3714 (0.4685)	−0.2000 (0.7040)

Source: Own study.

Table 10. Spearman's rank correlations calculated for financial information.

Disclosure	Total Assets (PLN)		Financial Result		Equity Capital	
	2019	2020	2019	2020	2019	2020
Elements at the input	0.6286 (0.1813)	−0.5000 (0.3125)	−0.8286 (0.0416)	0.0143 (0.9786)	0.2857 (0.5831)	−0.2143 (0.6835)
Business activities	0.5429 (0.2657)	−0.3286 (0.5249)	−0.6000 (0.2080)	0.1857 (0.7246)	0.5429 (0.2657)	0.1286 (0.8082)
Output effects	0.7143 (0.1108)	−0.3143 (0.5441)	−0.2857 (0.5831)	0.2000 (0.7040)	0.5571 (0.2508)	0.0429 (0.9358)
Results	0.8429 (0.0351)	−0.2429 (0.6429)	−0.3571 (0.4871)	0.2714 (0.6029)	0.5571 (0.2508)	0.0429 (0.7662)

(In brackets the *p*-value for the Spearman's coefficient significance test was given). Source: Own study.

The overall impact of the considered components on the enterprise's value against the background of the parameters published by the analyzed companies describing their financial situation indicated a statistically significant (with p-value < 0.05) relationship between the sum of assets and results and between the financial result and inputs and overall values of the components. At the same time, it should be noted that these relationships were only significant in 2019. In 2020, in each case, a decrease was observed in the strength of the relationship between the total value of the components and the financial situation of the company described by the parameters, such as total assets, financial result, or equity capital. In the case of total assets, there was also a change in the direction of the relationship from positive in 2019 to negative in 2020, while there was a substantially reverse change in the relationship from negative to positive in the case of the financial result (Hypothesis 2). Table 10 presents the correlations between pure financial disclosures. It should be noted that companies should include business model disclosures in the annual report, strategic plan, or sustainability report [93,94] There should be a separate section about the business model in reports or investor presentations. In this section, companies should explain how they generate revenue, create value for their customers, and plan to sustain their competitive advantage.

When examining the relationship between individual financial components and the financial parameters discussed, statistically significant relationships were only observed in 2019. These dependencies concerned the relationship between all the results and the sum of assets as well as the values of input elements and the financial result achieved by the examined companies. As in the case of the total components, there was a change in the direction of dependence in 2020 compared to 2019 for the relationship between individual components and the sum of assets and the financial result.

To sum up this stage of the research, our findings indicate that disclosures about the business model do not represent a significant value for the energy sector (Hypothesis 5). In disclosures about the business model, this sector does not perceive categories that create value for the enterprise. Studies have shown that companies that provide more detailed and transparent information about their business model in their financial reports tend to be viewed as more valuable by investors and other stakeholders (Hypothesis 5) [46,47,92]. Further research in this area should be carried out, taking into account the outbreak of the COVID-19 pandemic and looking for determinants that contribute to this state of affairs. Generally, the structures of the annual reports and sustainability reports of companies in the energy sector can be quite diverse, making it difficult to compare financial and non-financial data across different companies. Some companies may provide detailed information about their environmental and social performance in their sustainability reports, while others may not (Hypothesis 3).

6. Conclusions

The business model has been identified by the International Integrated Reporting Council (IIRC) as a basic element of integrated reporting, and integrated reporting should focus on the business model of a given enterprise, including its resources, relationships, and financial and non-financial aspects. It was also found that investors promote the position that high-quality reporting describing an enterprise's business model is essential in better understanding its performance, the impact of the external environment on the entity, and how entities create and "maintain" value. Our research allowed us to determine the framework, place, and detailed characteristics of the business model in corporate reporting in the energy sector.

Enterprises in the energy sector disclose financial and non-financial information in financial statements and reports of the management board on the activities of the company and the capital group. Only one company published an integrated report that included information about the business model (partial and only for 2019). Because these entities did not draw up integrated reports, they did not directly use the business model concept or indicate the characteristic components of the business model in their reports. Thus, the main objective of the study was achieved, i.e., we defined the framework, place, and detailed characteristics of the business model in corporate reporting in the energy sector. Our research recommends that the current state of companies in the energy sector in the WIG20 index be verified in order to implement integrated reports. Therefore, in addition to financial information, non-financial information regarding corporate social responsibility should be disclosed by these companies. This finding coincides with research conducted by ref. [95] recommending that sustainable business models should adopt the circular economy concept and report on biodiversity and extinction accounting in a more structured and mandatory way via producing integrated reports.

Companies in the energy sector most often disclose information about financial and productive capital. They rarely disclose information regarding the category of business activity, indicating mainly the risk related to the business they conduct. Companies in the energy sector are reluctant to disclose information about by-products and waste, both in financial and descriptive terms. In terms of results, the surveyed companies in the energy sector practically do not disclose information about the effects of research and development, employee development and employment creation, environmental impact, and customer satisfaction. Financial statements and the management board's report on the company's activities are obligatory documents legitimized by the Accounting Act. Therefore, it should be noted that the structure of the reports published by companies in the energy sector should be homogeneous to allow for easy comparison of financial data (Hypothesis 3). Companies in the energy sector have a diverse set of business models, for the generation and distribution of electricity, natural gas, oil exploration and production, and renewable energy projects, among others (Hypothesis 4) [93,94].

Our research shows that companies in the energy sector included in the WIG20 index do not disclose information about their business model in their annual reports. There is little descriptive content regarding the business model in the analyzed documents. This information is very important for making investment decisions by stock investors. The listed companies, in particular, should publish qualitative descriptive information in their reports. Emphasis on publishing relevant information about the business model would help to strengthen the knowledge and decision-making process of report recipients.

It should be emphasized that this was a pilot study, and the originality of this research is in focusing attention on the disclosure and reporting of information about the business model in corporate reports of the energy sector in Poland. This is the first such study in Poland conducted on companies in the energy sector; therefore it is treated by the authors as a pilot study. The research showed that companies in the energy sector included in the WIG20 index do not disclose information about the business model in their reports and the structure of the published reports is very diverse, making it even more difficult to compare financial and non-financial data. Therefore, it should be clearly emphasized that the results of the study, unfortunately, cannot be generalized. The main limitations of the study were the size of the research sample, despite focusing on the largest "list players" belonging to the WIG20 index in Poland, and the availability and quality of the financial and non-financial information about the business models presented in the reports of the energy companies and their indicated dispersion. The theoretical implication of the study includes the influence of the business model on the strategic and financial performance of companies. For example, a company that utilizes a decentralized business model may have a greater ability to respond quickly to changes in the market and adapt to new technologies, leading to improved performance. In practice, such companies may, for example:

- place a greater emphasis on metrics related to distributed energy resources and flexibility,
- focus more on traditional metrics, such as capacity factor and generation output.

Additionally, the choice of business model can also impact the regulatory environment in which energy companies operate, as different models may be subject to different rules and regulations. In terms of reporting, the business model can affect the level of transparency and disclosure of information to stakeholders, such as investors and regulators.

Author Contributions: Conceptualization, B.S., M.W.-J., G.Z., A.L., R.W. and N.S.; Data curation, B.S., M.W.-J., G.Z., N.S. and A.L.; Formal analysis, B.S., M.W.-J., G.Z., A.L., R.W. and N.S.; Funding acquisition, B.S., M.W.-J., R.W., G.Z., A.L. and N.S.; Methodology, B.S., M.W.-J., G.Z., N.S., R.W. and A.L.; Project administration, B.S., M.W.-J., G.Z., A.L., R.W. and N.S.; Resources, B.S., M.W.-J., G.Z., A.L., R.W. and N.S.; Software, B.S., M.W.-J., G.Z. and A.L.; Supervision, B.S., M.W.-J., G.Z. and A.L.; Validation, B.S., G.Z., M.W.-J., A.L., R.W. and N.S.; Visualization, B.S., M.W.-J. and G.Z.; Writing—original draft, B.S., M.W.-J., G.Z., A.L., N.S. and R.W.; Writing—review and editing, B.S., M.W.-J., G.Z., A.L., R.W. and N.S. All authors have read and agreed to the published version of the manuscript.

Funding: This project was co-financed within the framework of the program of the Ministry of Science and Higher Education under the "Regional Initiative of Excellence" in 2019–2022 (project number 018/RID/2018/19, amount of funding PLN 10 788 423,16) and the Research Excellence Program (contract no. 013/ZZR/2022/DOS).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The work was carried out as part of the statutory activity of the University of Szczecin, Cracow University of Economics, University of Lodz, Rzeszow University of Technology, and Jan Kochanowski University in Kielce.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gambardella, A.; McGahan, A. Business-Model Innovation: General Purpose Technologies and their Implications for Industry Structure. *Long Range Plan.* **2010**, *43*, 262–271. [CrossRef]
2. Debelak, D. *Business Model Made Easy*; McGraw-Hill Companies, Inc.: New York, NY, USA, 2006; 240p.
3. Fox, S.; Vahala, P. Start-Ups as Adaptable Stable Systems Based on Synchronous Business Models. *Systems* **2022**, *10*, 81. [CrossRef]
4. Henten, A.; Windekilde, I. Demand-Side Economies of Scope in Big Tech Business Modelling and Strategy. *Systems* **2022**, *10*, 246. [CrossRef]
5. Jablonski, A.; Jablonski, M. Business Models in Water Supply Companies-Key Implications of Trust. *Int. J. Environ. Res. Public Health* **2020**, *17*, 2770. [CrossRef]
6. Sjödin, D.; Parida, V.; Jovanovic, M.; Visnjic, I. Value Creation and Value Capture Alignment in Business Model Innovation: A Process View on Outcome Based Business Models. *J. Prod. Innov. Manag.* **2020**, *37*, 158–183. [CrossRef]
7. Pimenowa, O.; Pimenov, S.; Fyliuk, H.; Sitnicki, M.W.; Kolosha, V.; Kurinskyi, D. Sustainable Business Model of Modern Enterprises in Conditions of Uncertainty and Turbulence. *Sustainability* **2023**, *15*, 2654. [CrossRef]
8. Ivashkiv, I.; Kupalova, H.; Goncharenko, N.; Andrusiv, U.; Streimikis, J.; Lyashenko, O.; Yakubiv, V.; Lyzun, M.; Lishchynskyi, I.; Saukh, I. Environmental Responsibility as a Prerequisite for Sustainable Development of Agricultural Enterprises. *Manag. Sci. Lett.* **2020**, *10*, 2973–2984. [CrossRef]
9. Daradkeh, M. The Nexus between Business Analytics Capabilities and Knowledge Orientation in Driving Business Model Innovation: The Moderating Role of Industry Type. *Informatics* **2023**, *10*, 19. [CrossRef]
10. Franco, M.; Minatogawa, V.; Quadros, R. How Transformative Business Model Renewal Leads to Sustained Exploratory Business Model Innovation in Incumbents: Insights from a System Dynamics Analysis of Case Studies. *Systems* **2023**, *11*, 60. [CrossRef]
11. Teece, D.J. Business Models, Business Strategy, and Innovation. *Long Range Plan.* **2010**, *43*, 172–194. [CrossRef]
12. Bilan, Y. Increase Diversification Through Strengthened Enabling Environment for Entrepreneurship: A Focus on Skill Endowments and Export Orientation (Example of Hungary and Poland). *Econ. Sociol.* **2009**, *2*, 33–45. [CrossRef]
13. Garetti, M.; Taisch, M. Sustainable manufacturing: Trends and research challenges. *Prod. Plan. Control* **2012**, *23*, 83–104. [CrossRef]
14. Mettler, M. Blockchain technology in healthcare: The revolution starts here. In Proceedings of the 2016 IEEE 18th International Conference on E-Health Networking, Applications, and Services (Healthcom), Munich, Germany, 14–16 September 2016. [CrossRef]
15. Di Carlo, E.; Fortuna, F.; Testarmata, S. Boundaries of the business model within business groups. *J. Manag. Gov.* **2016**, *20*, 321–362. [CrossRef]
16. Barnabè, F. Representing' value creation: A combined approach of system dynamics and integrated reporting for the airline sector. *Int. J. Appl. Syst. Stud.* **2016**, *6*, 202–222. [CrossRef]
17. Barnabè, F.; Giorgino, M.C. Integrating business model and strategy. In *Integrated Reporting: Concepts and Cases that Redefine Corporate Accountability*; Springer: Cham, Switzerland, 2013; pp. 111–126. [CrossRef]
18. Bek-Gaik, B.; Rymkiewicz, B. Business Model in the Organization Reporting-assessment Disclosure in the Management Commentary. Zeszyty Naukowe Uniwersytetu Szczecińskiego. *Finans. Rynk. Finans. Ubezpieczenia* **2017**, *85*, 189–202. [CrossRef]
19. von Alberti-Alhtaybat, L.; Alhatabat, Z.; Al-Htaybat, K. Investigating the sustainability habitus: Insights from Aramex's sustainability practices and reports. *Meditari Account. Res.* **2020**, *29*, 477–501. [CrossRef]
20. Maniora, J. Is Integrated Reporting Really the Superior Mechanism for the Integration of Ethics into the Core Business Model? An Empirical Analysis. *J. Bus. Ethics* **2017**, *140*, 755–786. [CrossRef]
21. Dameri, R.P.; Ferrando, P.M. Implementing integrated reporting to disclose intellectual capital in health organizations: A case study. *J. Intellect. Cap.* **2021**, *22*, 311–336. [CrossRef]
22. Dameri, R.P.; Ferrando, P.M. Value creation disclosure: The international integrated reporting framework revisited in the light of stakeholder theory. *Meditari Account. Res.* **2021**. *ahead-of-print*. [CrossRef]
23. Roslender, R.; Nielsen, C. Accounting for the value expectations of customers: Re-imagining the Integrated Reporting initiative. *Crit. Perspect. Account.* **2020**, *81*, 102244. [CrossRef]
24. Kurochkina, I.; Shuvalova, E.; Novozhilova, I. About Formation of the Integrated Reporting Performance in the Process of Building a Sustainable Business of Transport and Communication Companies. *Procedia Eng.* **2017**, *178*, 267–277. [CrossRef]
25. Abela, M. Paradise Lost: Accounting Narratives without Numbers. *Account. Econ. Law Conviv.* **2020**, *10*. [CrossRef]
26. Amit, R.; Zott, C. Value creation in e-business. *Strateg. Manag. J.* **2001**, *22*, 493–520. [CrossRef]
27. Osterwalder, A.; Pigneur, Y. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*; John Wiley & Sons: Newyork, NY, USA, 2010; Volume 1.
28. Forge, S. Business models for the computer industry for the next decade. When will the fastest eat the largest? *Futures* **1993**, *25*, 923–948. [CrossRef]
29. Frehe, V.; Mehmann, J.; Teuteberg, F. Understanding and assessing crowd logistics business models–using everyday people for last mile delivery. *J. Bus. Ind. Mark.* **2017**, *32*, 75–97. [CrossRef]
30. Andreini, D.; Bettinelli, C.; Foss, N.J.; Mismetti, M. Innowacja modelu biznesowego: Przegląd literatury dotyczącej procesów. *J. Manag. Gov.* **2022**, *26*, 1089–1121. [CrossRef]
31. Lew, G.; Sadowska, B.; Chudy-Laskowska, K.; Zimon, G.; Wójcik-Jurkiewicz, M. Influence of Photovoltaic Development on Decarbonization of Power Generation—Example of Poland. *Energies* **2021**, *14*, 7819. [CrossRef]

32. Camilleri, M.A. Theoretical insights on integrated reporting: The inclusion of non-financial capitals in corporate disclosures. *Corp. Commun.* **2018**, *23*, 567–581. [CrossRef]
33. Caputo, F.; Pizzi, S.; Ligorio, L.; Leopizzi, R. Enhancing environmental information transparency through corporate social responsibility reporting regulation. *Bus. Strategy Environ.* **2021**, *30*, 3470–3484. [CrossRef]
34. Danaj, A.; Lazányi, K.; Bilan, Y. Perceptions and Implications of Immigration in France–Economic, Social, Political and Cultural Perspectives. *Econ. Sociol.* **2018**, *11*, 226–247. [CrossRef]
35. Casper, S.; Kettler, H. National institutional frameworks and the hybridization of entrepreneurial business models: The German and UK biotechnology sectors. *Ind. Innov.* **2001**, *8*, 5–30. [CrossRef]
36. Ciubotariu, M.S.; Socoliuc, M.; Grosu, V.; Mihaila, S.; Cosmulese, C.G. Modeling the relationship between integrated reporting quality and sustainable business development. *J. Bus. Econ. Manag.* **2021**, *22*, 1531–1550. [CrossRef]
37. Castillo, V.E.; Bell, J.E.; Rose, W.J.; Rodrigues, A.M. Crowdsourcing Last Mile Delivery: Strategic Implications and Future Research Directions. *J. Bus. Logist.* **2018**, *39*, 7–25. [CrossRef]
38. Christopher, M.; Lee, H. Mitigating supply chain risk through improved confidence. *Int. J. Phys. Distrib. Logist. Manag.* **2004**, *34*, 388–396. [CrossRef]
39. Dumitru, M.; Dyduch, J.; Gușe, R.G.; Krasodomska, J. Corporate Reporting Practices in Poland and Romania–An Ex-ante Study to the New Non-financial Reporting European Directive. *Account. Eur.* **2017**, *14*, 279–304. [CrossRef]
40. Hassan, A.; Elamer, A.A.; Lodh, S.; Roberts, L.; Nandy, M. The future of non-financial businesses reporting: Learning from the Covid-19 pandemic. *Corp. Soc. Responsib. Environ. Manag.* **2021**, *28*, 1231–1240. [CrossRef]
41. Ignatowski, R.; Sadowska, B.; Wójcik-Jurkiewicz, M. *Oblicza Raportowania w Perspektywie Środowiskowej*; Instytut Prawa Gospodarczego: Katowice, Poland, 2020.
42. Krasodomska, J.; Michalak, J.; Świetla, K. Directive 2014/95/EU: Accountants' understanding and attitude towards mandatory non-financial disclosures in corporate reporting. *Meditari Account. Res.* **2020**, *28*, 751–779. [CrossRef]
43. Krasodomska, J.; Zieniuk, P.; Kostrzewska, J. Reporting on Sustainable Development Goals in the European Union: What Drives Companies' Decisions? *Compet. Rev.* **2022**, *33*, 120–146. [CrossRef]
44. Krasodomska, J.; Zieniuk, P. Atestacja informacji niefinansowych: Podstawy teoretyczne, standardy i praktyki spółek działających w Europie Zachodniej i Wschodniej. *Zesz. Teor. Rachun.* **2021**, *45*, 53–74.
45. Mamcarczyk, M.; Popławski, Ł.; Zieniuk, P. Key Audit Matters in the Auditor's Reports on the Example of European Mining Companies. *Acta Montan. Slovaca* **2020**, *25*, 453–465.
46. Kannenberg, L.; Schreck, P. Integrated Reporting: Bonn or Bane? A Review of Empirical Research on Its Determinants and Implications. *J. Bus. Econ.* **2019**, *89*, 515–567. [CrossRef]
47. Jensen, J.C.; Berg, N. Determinants of Traditional Sustainability Reporting versus Integrated Reporting. An Institutionalist Approach. *Bus. Strategy Environ.* **2012**, *21*, 299–316. [CrossRef]
48. Szulc, M.; Zieniuk, P. The Disclosure of Events after the Reporting Period: The Example of Listed Companies from Selected European Countries. *Zesz. Teor. Rachun.* **2020**, *109*, 139–155. [CrossRef]
49. Eccles, R.G.; Serafeim, G.; Krzus, M.P. Market Interest in Nonfinancial Information. *J. Appl. Corp. Financ.* **2011**, *23*, 113–127. [CrossRef]
50. European Financial Reporting Advisory Group Discussion Paper: Towards a Disclosure Framework for the Notes, Discussion Paper. Available online: https://www.efrag.org/Assets/Download?assetUrl=%2Fsites%2Fwebpublishing%2FSiteAssets%2F121015_Disclosure_Framework_-_FINAL1.pdf (accessed on 28 March 2022).
51. ICAEW Business Models in Accounting: The Theory of the Firm and Financial Reporting. 2010. Available online: https://www.icaew.com/technical/financial-reporting/information-for-better-markets/ifbm-reports/business-models-in-accounting-the-theory-of-the-firm-and-financial-reporting (accessed on 30 December 2010).
52. Jutla, D.; Bodorik, P.; Wang, Y. Developing Internet e-commerce benchmarks. *Inf. Syst.* **1999**, *24*, 475–493. [CrossRef]
53. Drożdż, W.; Kinelski, G.; Czarnecka, M.; Wójcik-Jurkiewicz, M.; Maroušková, A.; Zych, G. Determinants of Decarbonization—How to Realize Sustainable and Low Carbon Cities? *Energies* **2021**, *14*, 2640. [CrossRef]
54. Kaszyński, P.; Komorowska, A.; Zamasz, K.; Kinelski, G.; Kamiński, J. Capacity Market and (The Lack of) New Investments: Evidence from Poland. *Energies* **2021**, *14*, 7843. [CrossRef]
55. Lisiński, M.; Sroka, W.; Brzeziński, P.; Jabłoński, A.; Stuglik, J. Application of Modern Management Concepts by Polish Companies-Analysis of Research Results. *Organizacija* **2012**, *45*. [CrossRef]
56. Köhler, J.; Geels, F.W.; Kern, F.; Markard, J.; Onsongo, E.; Wieczorek, A.; Alkemade, F.; Avelino, F.; Bergek, A.; Boons, F.; et al. An Agenda for Sustainability Transitions Research: State of the Art and Future Directions. *Environ. Innov. Soc. Transit.* **2019**, *31*, 1–32. [CrossRef]
57. Shakeel, J.; Mardani, A.; Chofreh, A.G.; Goni, F.A.; Klemeš, J.J. Anatomy of sustainable business model innovation. *J. Clean. Prod.* **2020**, *261*, 121201. [CrossRef]
58. Mucha-Kuś, K.; Sołtysik, M.; Zamasz, K.; Szczepańska-Woszczyna, K. Coopetitive Nature of Energy Communities—The Energy Transition Context. *Energies* **2021**, *14*, 931. [CrossRef]
59. Jasiński, J.; Kozakiewicz, M.; Sołtysik, M. Determinants of Energy Cooperatives' Development in Rural Areas—Evidence from Poland. *Energies* **2021**, *14*, 319. [CrossRef]

60. Wójcik-Jurkiewicz, M.; Czarnecka, M.; Kinelski, G.; Sadowska, B.; Bilińska-Reformat, K. Determinants of Decarbonisation in the Transformation of the Energy Sector: The Case of Poland. *Energies* **2021**, *14*, 1217. [CrossRef]
61. Ramdani, B.; Binsaif, A.; Boukrami, E. Business model innovation: A review and research agenda. *N. Engl. J.Entrep.* **2019**, *22*, 89–108. [CrossRef]
62. Mucha-Kuś, K.; Czakon, W.; Sołtysik, M. Coopetitive Platform: Common Benefits in Electricity and Gas Distribution. *Energies* **2021**, *14*, 7113. [CrossRef]
63. Dyduch, W.; Chudziński, P.; Cyfert, S.; Zastempowski, M. Dynamic Capabilities, Value Creation and Value Capture: Evidence from SMEs under Covid-19 Lockdown in Poland. *PLoS ONE* **2021**, *16*, e0252423. [CrossRef]
64. Dobrowolski, Z.; Sułkowski, Ł. Business Model Canvas and Energy Enterprises. *Energies* **2021**, *14*, 7198. [CrossRef]
65. Czarnecka, M.; Chudy-Laskowska, K.; Kinelski, G.; Lew, G.; Sadowska, B.; Wójcik-Jurkiewicz, M.; Budka, B. Grants and Funding for the Processes of Decarbonization in the Scope of Sustainability Development—The Case from Poland. *Energies* **2022**, *15*, 7481. [CrossRef]
66. Ciołek, M.; Emerling, I.; Olejko, K.; Sadowska, B.; Wójcik-Jurkiewicz, M. Assumptions of the Energy Policy of the Country versus Investment Outlays Related to the Purchase of Alternative Fuels: Poland as a Case Study. *Energies* **2022**, *15*, 1945. [CrossRef]
67. Toborek-Mazur, J.; Wójcik-Jurkiewicz, M. Multi-Energy Concern as an Example of the Implementation of Agenda 2030: Poland as a Case Study. *Energies* **2022**, *15*, 1669. [CrossRef]
68. Vaska, S.; Massaro, M.; Bagarotto, E.M.; Dal Mas, F. The Digital Transformation of Business Model Innovation: A Structured Literature Review. *Front. Psychol.* **2021**, *11*, 539363. [CrossRef] [PubMed]
69. Toborek-Mazur, J.; Partacz, K.; Surówka, M. Energy Security as a Premise for Mergers and Acquisitions on the Example of the Multi-Energy Concern PKN Orlen in the Face of the Challenges of the 2020s. *Energies* **2022**, *15*, 5112. [CrossRef]
70. Morchain, D. Rethinking the framing of climate change adaptation. Knowledge, power, and politics. In *A Critical Approach to Climate Change Adaptation. Discourses, Policies, and Practices*; Klepp, S., Chavez Rodriguez, L., Eds.; Routledge: New York, NY, USA; Oxon, UK, 2018; pp. 55–73.
71. Rosenzweig, C.; Solecki, W.D.; Hammer, S.A.; Mehrotra, S.S. *Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network*; Cambridge University Press: Cambridge, UK, 2011.
72. Simonet, G.; Fatorić, S. Does "adaptation to climate change" mean resignation or opportunity? *Reg. Environ. Chang.* **2016**, *16*, 789–799. [CrossRef]
73. Kaczmarek, J.; Kolegowicz, K.; Szymla, W. Restructuring of the Coal Mining Industry and the Challenges of Energy Transition in Poland (1990–2020). *Energies* **2022**, *15*, 3518. [CrossRef]
74. Pietruszka-Ortyl, A.; Ćwiek, M.; Ziębicki, B.; Wójcik-Karpacz, A. Organizational Culture as a Prerequisite for Knowledge Transfer among IT Professionals: The Case of Energy Companies. *Energies* **2021**, *14*, 8139. [CrossRef]
75. Bielińska-Dusza, E.; Hamerska, M.; Żak, A. Sustainable Mobility and the Smart City: A Vision of the City of the Future: The Case Study of Cracow (Poland). *Energies* **2021**, *14*, 7936. [CrossRef]
76. Sovacool, B.K. Reckless or righteous? Reviewing the sociotechnical benefits and risks of climate change geoengineering. *Energy Strat. Rev.* **2021**, *35*, 100656. [CrossRef]
77. Sovacool, B.K.; Martiskainen, M.H.A.; Baker, L. Beyond cost and carbon: The multidimensional co-benefits of low carbon transitions in Europe. *Ecol. Econ.* **2020**, *169*, 106529. [CrossRef]
78. Lassini, U.; Lionzo, A.; Rossignoli, F. Does business model affect accounting choices? An empirical analysis of European listed companies. *J. Manag. Gov.* **2016**, *20*, 229–260. [CrossRef]
79. Marchet, G.; Melacini, M.; Sassi, C.; Tappia, E. Assessing efficiency and innovation in the 3PL industry: An empirical analysis. *Int. J. Logist. Res. Appl.* **2017**, *20*, 53–72. [CrossRef]
80. Melloni, G.; Stacchezzini, R.; Lai, A. The tone of business model disclosure: An impression management analysis of the integrated reports. *J. Manag. Gov.* **2016**, *20*, 295–320. [CrossRef]
81. Nielsen, C.; Lund, M.; Montemari, M.; Paolone, F.; Massaro, M.; Dumay, J. *Business Models: A Research Overview*; Routledge: London, UK, 2018.
82. Singleton-Green, B. Should financial reporting reflect firms' business models? What accounting can learn from the economic theory of the firm. *J. Manag. Gov.* **2014**, *18*, 697–706. [CrossRef]
83. Di Tullio, P.; Valentinetti, D.; Nielsen, C.; Rea, M.A. In search of legitimacy: A semiotic analysis of business model disclosure practices. *Meditari Account. Res.* **2020**, *28*, 863–887. [CrossRef]
84. Di Vaio, A.; Syriopoulos, T.; Alvino, F.; Palladino, R. Integrated thinking and reporting' towards sustainable business models: A concise bibliometric analysis. *Meditari Account. Res.* **2020**, *29*, 691–719. [CrossRef]
85. Veleva, V.; Bodkin, G. Corporate-entrepreneur collaborations to advance a circular economy. *J. Clean. Prod.* **2018**, *188*, 20–37. [CrossRef]
86. Siksnelyte-Butkiene, I.; Streimikiene, D. Sustainable Development of Road Transport in the EU: Multi-Criteria Analysis of Countries' Achievements. *Energies* **2022**, *15*, 8291. [CrossRef]
87. Borys, T.; Bugdol, M.; Puciato, D. Barriers to achieving climate goals. An external context. *Ekon. Sr. Econ. Environ.* **2022**, *82*, 8–37. [CrossRef]
88. Ford, J.D.; Berrang-Ford, L.; Lesnikowski, A.; Barrera, M.; Heymann, S.J. How to track adaptation to climate change: A typology of approaches for national-level application. *Ecol. Soc.* **2013**, *18*, 40. [CrossRef]

89. Broniewicz, E.; Bukowska, J.; Godlewska, J.; Lulewicz-Sas, A.; Sidorczuk-Pietraszko, E. Climate change adaptation in ex-ante assessment of legal acts—A proposal of indicators for Poland. *Econ. Environ.* **2022**, *82*, 52–73. [CrossRef]
90. Romanowska, A.; Pangsy-Kania, S.; Budzyński, M.; Wierzbicka, K.; Prystrom, J. Determinants and effects of Poland's road accidents in the context of the 2030 agenda for sustainable development–poviat level analysis for the years 2010–2019. *Econ. Environ.* **2022**, *82*, 173–193. [CrossRef]
91. Borys, G. Rough assessment of the consideration of spatial planning tools in the municipal plans for adaptation to climate change. An example of selected Polish cities. *Econ. Environ.* **2022**, *80*, 22–38. [CrossRef]
92. Aylett, A. Institutionalising the urban governance of climate change adaptation: Results of an international survey. *Urban Clim.* **2015**, *14*, 4–16. [CrossRef]
93. Penarroya-Farell, M.; Miralles, F. Business Model Dynamics from Interaction with Open Innovation. *J. Open Innov. Technol. Mark. Complex.* **2021**, *7*, 81. [CrossRef]
94. Bartoszewicz, A.; Szczepankiewicz, E. Evolution of Energy Companies' Non-Financial Disclosures: A Model of Non-Financial Reports in the Energy Sector. *Energies* **2022**, *15*, 7667. [CrossRef]
95. Sinkovics, N.; Gunaratne, D.; Sinkovics, R.R.; Molina-Castillo, F. Sustainable Business Model Innovation: An Umbrella Review. *Sustainability* **2021**, *13*, 7266. [CrossRef]

energies

Article

Regional Specialization, Competitive Pressure, and Cooperation: The Cocktail for Innovation

Bartolomé Marco-Lajara, Eduardo Sánchez-García *, Javier Martínez-Falcó and Esther Poveda-Pareja

Department of Business Organization, University of Alicante, 03690 San Vicente del Raspeig, Spain; bartolome.marco@ua.es (B.M.-L.); javier.falco@ua.es (J.M.-F.); esther.poveda@ua.es (E.P.-P.)
* Correspondence: eduardo.sanchez@ua.es; Tel.: +34-96-590-3400 (ext. 3153)

Abstract: The main aim of this paper is to analyze the effect of industrial agglomeration on the degree of interorganizational cooperation and the innovative performance of firms of the electricity supply sector in Spain. For this purpose, the agglomeration coefficient in each of the 50 provinces of Spain is calculated, based on secondary data from SABI database. Subsequently, primary data are obtained from a sample of 197 companies through a structured questionnaire. In this case, the PLS-SEM technique is used. The results show that there is a positive and significant relationship between the variables analyzed. It is concluded that industrial agglomeration and cooperation are relevant external factors that boost the innovative performance of firms and that business associations foster interorganizational cooperation.

Keywords: agglomeration; cluster; specialization; cooperation; innovation; PLS-SEM; energy

JEL Classification: R12; O36; R30; L94

Citation: Marco-Lajara, B.; Sánchez-García, E.; Martínez-Falcó, J.; Poveda-Pareja, E. Regional Specialization, Competitive Pressure, and Cooperation: The Cocktail for Innovation. *Energies* **2022**, *15*, 5346. https://doi.org/10.3390/en15155346

Academic Editors: Bernard Ziębicki and Edyta Bielińska-Dusza

Received: 22 June 2022
Accepted: 20 July 2022
Published: 23 July 2022

1. Introduction

Innovation is a fundamental factor for economic development and favors the generation and exploitation of opportunities by companies and boosts their performance [1–3]. Its importance has increased in recent years in academia, as a fundamental factor for the survival, and competitiveness of firms [4–6]. The development of innovations requires the interaction and cooperation of multiple actors in terms of information, knowledge, and other resources in favor of particular social or economic goals [7,8]. Cooperation allows organizations to analyze the market situation, generate new ideas, and expand their knowledge base on an ongoing basis [9]. In this way, the establishment of reciprocal cooperative relationships favors the absorption of knowledge by the participating companies and its application to the development of innovations [10,11]. Thus, the exchange of knowledge with agents in the environment is essential to boost the innovative performance of firms [12,13].

Industrial agglomeration favors communication and the establishment of cooperative–competitive relationships between companies in the sector (whether direct competitors or not) that are located geographically close to each other, which reduces the costs and risks of the process and has positive effects on communication, the generation of trust, access to and creation of new knowledge, and innovative performance [14,15]. In this sense, Porter [16] highlights a driver of innovation—in addition to the intensity of local competition— as being the existence of greater opportunities for cooperation. In this regard, there are certain agents, such as business associations, that facilitate the implementation of joint innovation processes acting as intermediary entities [17,18]. Belonging to an association of entrepreneurs promotes interaction and cooperation among its members, and favors the establishment of relationships of trust, acting as a tool of cohesion and intermediation [17], which favors the acquisition and assimilation of new knowledge [19].

In this research paper we study the influence of the agglomeration of the sector on the innovative performance of firms. In addition, we analyze the mediating effect of the degree of cooperation in this relationship and the membership of an association of entrepreneurs as an antecedent variable of the degree of the cooperation of firms with entities in their environment. Specifically, the aim of this paper is to determine the effect of industrial agglomeration on the innovative performance of firms in the sector under study, and the influence of cooperation as a mediating variable in this relationship.

The analysis is carried out in two phases. In the first one, data of the electricity supply sector were extracted from the SABI database, from which the number of companies and employment in each of the 50 provinces that make up the Spanish territory were calculated. Based on this data, the degree of agglomeration of the sector in each province was calculated in relation to the national average. Subsequently, in the second phase, a theoretical model was developed based on the hypotheses put forward. A structured questionnaire was designed, composed of validated scales for the calculation of the variables included in the proposed model, and was distributed among the companies of the sector being studied, obtaining a total of 197 valid responses, and the use of the PLS-SEM method was chosen to estimate the proposed relationships. Specifically, the responses were coded and analyzed using the SmartPLS software, in its version 3.3.3, SmartPLS GmbH, Oststeinbek, Germany.

The structure of the research is the following. First, there is a review of the literature related to the studied variables and relationships, from which the research hypotheses and the nomogram of the model are proposed. Then, the methodology used is described and, later, the results of the study are set out. Finally, the results are discussed, and the conclusion drawn, emphasizing the necessity to further deepen the analysis of the effects of closeness and cooperation dynamics on innovation.

2. Literature Review

2.1. Industrial Clustering and Innovation

Although by applying logic it could be determined that the accelerated process of the globalization of the economy, the reduction in the costs of transporting goods, and the development of information and communication technologies reduce the importance of location as a driver of business performance, the reality seems to indicate that the importance of the local environment has progressively increased [20] (p.256). Thus, nowadays the choice of the environment in which to locate business activities is a key strategic decision, which determines the characteristics of external agents that can favor the generation of certain localization economies and, consequently, a comparative advantage with respect to firms in geographically dispersed locations.

According to Baldwin and Von Hippel [21], it is essential to shift the focus of innovation generation and development from within firms to an open and collaborative path, in which firms and various agents and stakeholders, especially customers, work together in the design and development of innovations. This is because the capture of ideas and knowledge by companies through interaction with different specialized agents in the environment is a potential source of valuable resources that can lead to interesting opportunities for innovation [22]. In this sense, industrial agglomeration favors the generation of cooperative–competitive environments, in which the development of the relational networks of firms is promoted, alongside the pooling of a series of complementary resources and capabilities in favor of the achievement of shared objectives [23–25].

Moreover, productive specialization is one of the essential externalities derived from industrial agglomeration [26], which favors the technical specialization of processes and knowledge, not only of those companies dedicated to the industry in question, but also of those others that perform complementary activities [27]. In this sense, collaboration between various specialized economic agents, belonging to a given geographical area, increases the likelihood of the success of the innovation development processes undertaken by firms [28–30].

In addition, the exchange of knowledge between these specialized agents located geographically close to each other avoids duplication of efforts for the development of new knowledge and innovations [15]. Based on the above, the following hypothesis is proposed:

Hypothesis 1 (+): *There is a positive and significant relationship between the degree of agglomeration of the sector and the innovative performance of firms.*

2.2. Business Associations and Interorganizational Cooperation

According to Mejía-Villa, Tanco, and San Martín [19], the role of business associations as stimulators of innovation has been scarcely studied, despite the particularities conferred by their associative nature, which do not pursue lucrative purposes but simply defend the interests of their members and promote their positioning in the market, as well as enhance the dissemination of knowledge and the innovation capacity of their associates.

Business associations act as the promoters of collaborative innovation [19]. They are non-profit organizations [17] that usually bring together a large part of the entrepreneurs of a specific sector and region, in the first instance, exercising a certain degree of cohesion among them, in that their membership of the association is due to very similar motives and/or needs.

According to Nonaka and Konno [31], through continuous interaction at different levels between individuals and the sharing of their individual experiences, knowledge, and visions in a specific environment and time, the right conditions are established for the generation of trust, ideas, and new knowledge, as well as their development and integration. This can lead to the adoption of efficient, effective, and innovative solutions to their common problems. The effective development of open innovation processes requires that the communication channels work smoothly, as well as the existence of trust between the different individuals or agents involved in the process [32].

In this regard, socialization is an essential element for the generation of trust and the exchange and combination of ideas, information, and knowledge, especially tacit knowledge [33,34]. The latter is rooted in the experiences, aspirations, and values of individuals, which makes its dissemination difficult, although through continuous interaction between individuals in a specific place and time, its transfer can be promoted [31].

Zheng [35] concluded that various characteristics of the relational networks established by firms with agents in their environment, such as the strength of ties, trust, and shared norms and vision, can influence their ability to develop innovations. However, it is necessary to combine the agglomeration approach with other tools to accelerate results in terms of cooperation and innovation [36]. In this respect, business associations act as intermediary agents, favoring continuous interaction between entities with complementary resources and capabilities.

According to Sun, Zhang, and Zhang [37], the density of relational networks and the intensity of cooperation have a positive effect on the innovative performance of participants. Thus, they can influence the quality and quantity of cooperation agreements established by the company with agents in the environment and the transmission of tacit knowledge, especially among entities belonging to the association itself. Based on the above, the following hypothesis is proposed:

Hypothesis 2 (+): *There is a positive and significant relationship between active membership in a business association and the degree of cooperation of firms with surrounding agents.*

2.3. Industrial Clustering, Cooperation and Innovation

In today's knowledge society, access to external sources of valuable information and knowledge is essential for the survival of firms [38,39]. According to Audretsch, Hülsbeck, and Lehmann [40], collaborative networks contribute to the increased competitiveness of countries and regions through the pooling of resources and capabilities for the joint development of innovations.

Intangible resources based on knowledge drive the creation of value by companies [41] and favor their constant adaptation to current dynamic environments, in which it is difficult to make reliable forecasts [42]. This flexibility, in turn, facilitates access to new technologies and knowledge, as well as their assimilation and exploitation [43].

Geographical proximity does not automatically imply the establishment of cooperation agreements between entities located in a given region [44]. Interorganizational learning and the joint development of innovations seems to require, in addition to physical proximity, the existence of social and cognitive proximity between specialized economic agents located geographically close, which allows them to communicate effectively [45–47]. In this respect, industrial agglomeration implies the existence of a large number of entities that, in addition to being located geographically close, are specialized in a main industry, which can have a positive impact on social and cognitive proximity.

This can favor the membership of certain specialized social networks that, according to Alguezaui and Filieri [48], allows firms to access a wide set of valuable resources and capabilities shared by their members, especially new knowledge, which is an essential factor in the development of innovations.

Industrial agglomeration fosters the generation of a favorable environment for inter-firm cooperation [49]. The geographical proximity derived from industrial agglomeration fosters the generation of links between economic agents belonging to a main industry, and boosts the strength of relationships, trust, the existence of shared values, and the efficiency and effectiveness with which knowledge is transferred [50–52].

Thus, the interaction between individuals derived from collaboration with external agents allows firms to increase their knowledge base and establish mutually beneficial relationships [53–55]. By making constant efforts in this area, collective learning dynamics are generated that drive the development of innovations [56–58]. In particular, the effective exploitation of external knowledge sources has a positive effect on the innovative performance of firms [59].

Although studies linked to the analysis of the so-called "New Economic Geography" provide certain theoretical explanations in this regard [60], at present there is still some confusion when trying to determine which of the positive externalities generated by industrial agglomeration favor the development of firms and their innovative performance [61]. Thus, this paper proposes that cooperation is one of the main factors derived from industrial agglomeration that favors the innovative performance of firms. Based on this, the following hypothesis is proposed.

Hypothesis 3 (+): *The degree of cooperation of firms with surrounding agents mediates the relationship between the degree of agglomeration of the sector and the innovative performance of firms.*

3. Methodology

3.1. Population and Sample

The population being studied is made up of the companies belonging to the electricity supply sector in Spain. According to the "Sistema de Análisis de Balances Ibéricos (SABI)" database, the number of active companies in Spain for the year 2019 is 13,339.

The sample is comprised of 197 companies in the sector, located in different regions of Spain. Although this sector only employs 2% of the total number of workers in Spain, its activity generates 13.3% of the gross added value, which positions it as the second most important sector, being only surpassed by the "Food, beverages and tobacco" sector, as well as presenting the highest average productivity per employee (449,800 euros) (According to the data issued by the National Statistics Institute for the financial year 2017: https://www.ine.es/, accessed on 3 February 2022).

3.2. Data Collection and Measurement of Variables

The data used to test the hypotheses come from both primary and secondary sources. In relation to the former, the data were obtained through the design and distribution of a questionnaire to the companies in the population under study (The questionnaire is described in detail in Appendix A). A total of 11,757 emails were sent out, addressed to the companies' management staff, as they were considered to have a broad knowledge of the general functioning of the organization, as well as of the main decision-making bodies. The tools used for the design and distribution of the questionnaire were "Qualtrics" and "Microsoft Outlook" software, version January 2021, Qualtrics, Washington, DC, USA, respectively.

The questionnaire distribution process covered a period of 4 months, specifically from September to December 2020, during which, in addition to the initial mailing, several reminders were sent out, as well as telephone calls to encourage participants to collaborate with the research. After analyzing the completed questionnaires to determine their statistical validity, and after discarding any that were not considered valid (for different reasons, such as the existence of a large number of missing values, the presence of response patterns or a high number of single-value responses), a sample of 197 valid responses was collected. Hair, Hult, Ringle, and Sarstedt [62] establish, through their "minimum R^2" method, that for a minimum R^2 value of the model equal to 0.500 and a maximum number of predictors of 2, the minimum sample size is 33 cases.

Regarding the secondary sources, we used the SABI database to determine the degree of agglomeration of companies and employment in the sector, as it allows us to determine the exact number of employees per company, as well as the number of companies per province, which increases the precision of the study. Due to the peculiarities inherent to the territorial organization of Spain, we decided to take the province as the territorial delimitation. In this way, the fifty provinces and the autonomous cities of Ceuta and Melilla were considered.

Innovative performance (dependent variable): A 7-point Likert-type scale with 13 items was used to measure this reflective variable. Specifically, validated scales of 5, 4, 3, and 1 items were used to measure the innovative performance of product, process, marketing, and management, respectively, based on the works of Prajogo and Ahmed [63] and Škerlavaj, Song, and Lee [64].

Degree of agglomeration of the sector (independent variable): This formative variable determines the degree of concentration of the sector under study in each of the regions. The geographical concentration of firms is measured in different ways in the agglomeration literature. Some studies use the density of firms in each specific industry and geographical area [65–67], while others use employment data [68,69]. In this paper, both indicators were used to calculate this construct. This type of coefficient has been widely used in many empirical works related to the study of clusters. Although they are simple indicators, they make it possible to determine in a clear and comprehensible way the regional distribution of companies and employees belonging to a given sector or industry. As territorial units of analysis we used the 50 provinces and 2 autonomous cities of Spain. Once the territorial division was established, the degree of regional concentration of employment and companies in the sector was analyzed in relation to the national average, by using the following coefficient

$$AC = (a:b):(c:d) \tag{1}$$

where AC: agglomeration coefficient. a: Sector units at regional level. b: Total units at regional level. c: Sector units at national level. d: Total units at national level [65–69].

This coefficient should be interpreted as follows. Regions that present a value greater than 1 have a degree of concentration of employees and/or companies in the sector that is greater than the national average. The higher the value of the coefficient, the greater the degree of concentration in the region in question.

Cooperation (mediating variable): Firms mainly have access to new knowledge through internal development or from external sources [70]. In this line, several authors highlight the role of cooperation with accessible external sources as a tool that allows the generation of ideas and knowledge sharing and, consequently, favors the increase of the knowledge base of the participating companies [71–73]. Thus, it is proposed that the degree of cooperation between firms and the different nodes of their network of relationships can be favored by belonging to a business association. This paper proposes that cooperation mediates the relationship between the degree of agglomeration of the sector and the innovative performance of firms. This reflective variable refers to the extent to which firms cooperate with the main stakeholders in their environment (competing firms, suppliers, customers, universities, technology centers, and other entities). It was measured by means of a Likert-type scale of 7 points and 6 items, which was elaborated based on the work of Claver-Cortés, Marco-Lajara, and Manresa-Marhuenda [74].

Association (antecedent variable): According to Dalziel [17], associations are non-profit entities that bring together a high proportion of entrepreneurs in each sector and region. These associations defend the interests of their members and promote cooperation among them. Likewise, membership and participation in the association can favor the generation of relationships of trust between members, which in turn can influence their willingness to cooperate in a wide range of areas, pooling their resources and capabilities to achieve shared objectives. Association was established as an antecedent variable of cooperation. This reflective variable was measured by means of a 7-point Likert-type scale with 3 items, reflecting membership or not of an association and the type of participation, active or passive, of the associates.

3.3. Analysis Technique

To test the hypotheses, structural equation modelling (SEM) was used; specifically, the second-generation multivariate analysis technique of partial least squares (PLS), which according to Hair, Sarstedt, Pieper, and Ringle [75], has gained great relevance in recent years among researchers in the field of strategic management of the company.

For this purpose, the SmartPLS software, version 3.3.3 was used [76]. According to Hair, Hult, Ringle, Sarstedt, Castillo Apraiz, Cepeda Carrión, and Roldán [77], it is a suitable technique for predictive analytics, especially in the field of social sciences. In addition, it allows us to test models of linear relationships between variables, including those of a latent nature.

The PLS-SEM technique uses the maximization of the explained variance of the observable and unobservable variables to estimate the parameters of the established model [78]. According to these authors, due to the above, this technique is particularly suitable for research in the field of social sciences. It has been evidenced that the PLS-SEM method obtains greater flexibility and robustness than traditional approaches [79].

This method of analysis has been chosen for different reasons. Fundamentally, because the study is predictive in nature, making it suitable for the use of the PLS-SEM technique [80]. In addition, it is an efficient tool for the estimation of complex models, which allows working with relatively small sample sizes, and with data that do not follow a specific distribution [77].

Finally, the proposed model includes second-order latent variables, and the PLS technique allows us to efficiently estimate this type of multidimensional model [81].

4. Data Analysis and Results

4.1. Data Analysis and Results

The results of the first phase of analysis, relating to the distribution of the sector in Spain, are presented in Table 1 below. Specifically, the values corresponding to the degree of agglomeration of the sector (companies and employment) at the provincial level, in comparison with the national average, are shown. The distribution of the sample according to the degree of agglomeration of the sector in the province in which they are located, in relation to the national average, is also shown.

Table 1. Distribution of the sample in relation to the degree of agglomeration of the sector under study, in absolute and relative values.

Coefficient	Degree of Agglomeration of the Region	Number of Firms of the Sample	Percentage of the Sample
Employees	Higher than the national average	114 companies	57.87%
	Lower than the national average	83 companies	42.13%
Companies	Higher than the national average	112 companies	56.85%
	Lower than the national average	85 companies	43.15%

Table 2 details the distribution of the population of companies compared to the sample in relative terms, according to their location or not, in a region that presents agglomeration of firms or employment in the sector, in comparison with the national average.

Table 2. Comparison of the distribution of the population and the sample in relation to the degree of agglomeration of the sector under study, in relative values.

Coefficient	Degree of Agglomeration of the Region	Percentage of the Population	Percentage of the Sample
Employees	Higher than the national average	66.09%	57.87%
	Lower than the national average	33.91%	42.13%
Companies	Higher than the national average	66.62%	56.85%
	Lower than the national average	33.38%	43.15%

Table 3 shows brief descriptive statistics of the data obtained in the questionnaire.

Table 3. Descriptive statistic of the data obtained in the questionnaire.

	Mean	Min	Max	S.D.
Cooperation	4.396	1	7	1.726
Association	1.868	1	3	0.776
I.P.	4.809	1	7	1.590
D.A.S.	1.086	0.059	4.743	0.928

Note: D.A.S.: Degree of agglomeration of the sector. I.P.: Innovative performance. S.D.: Standard deviation.

Finally, Figures 1 and 2 show in detail the agglomeration coefficient of the sector under study in each of the provinces, in relation to the number of companies and employment, respectively. To facilitate its reading, a color range has been established, which varies from dark red, for levels of agglomeration much lower than the national average, to dark green, for high levels of agglomeration. The other colors indicate intermediate levels.

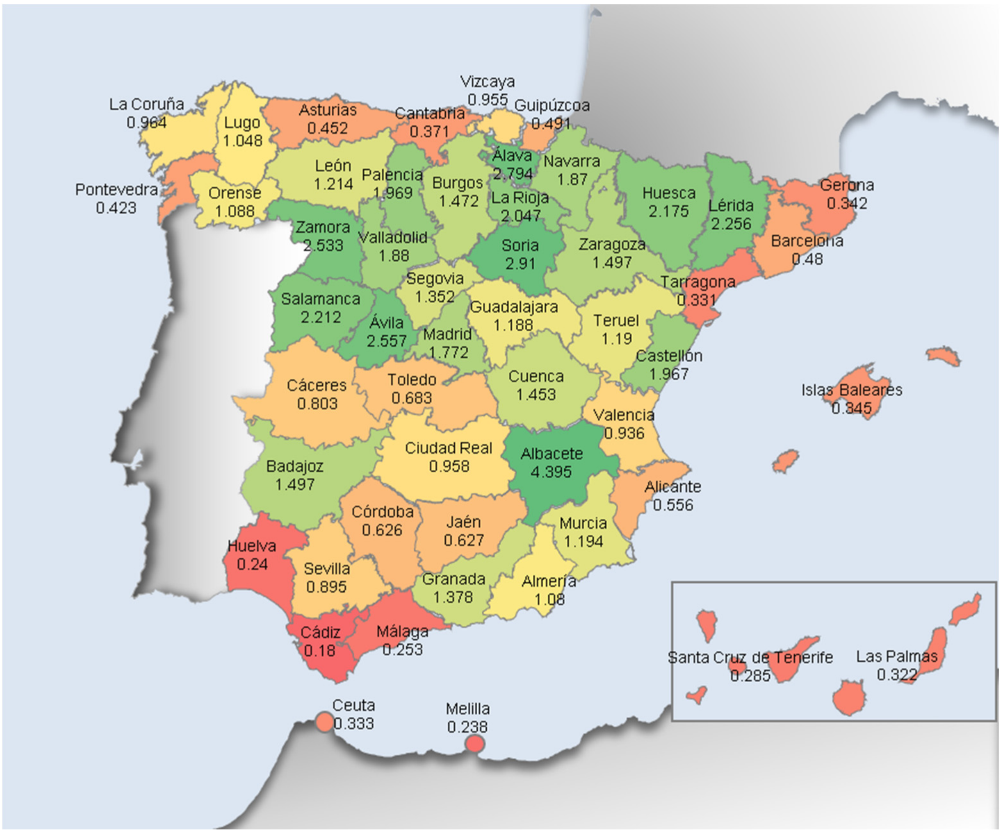


Figure 1. Degree of agglomeration of companies in the sector at the provincial level in Spain.

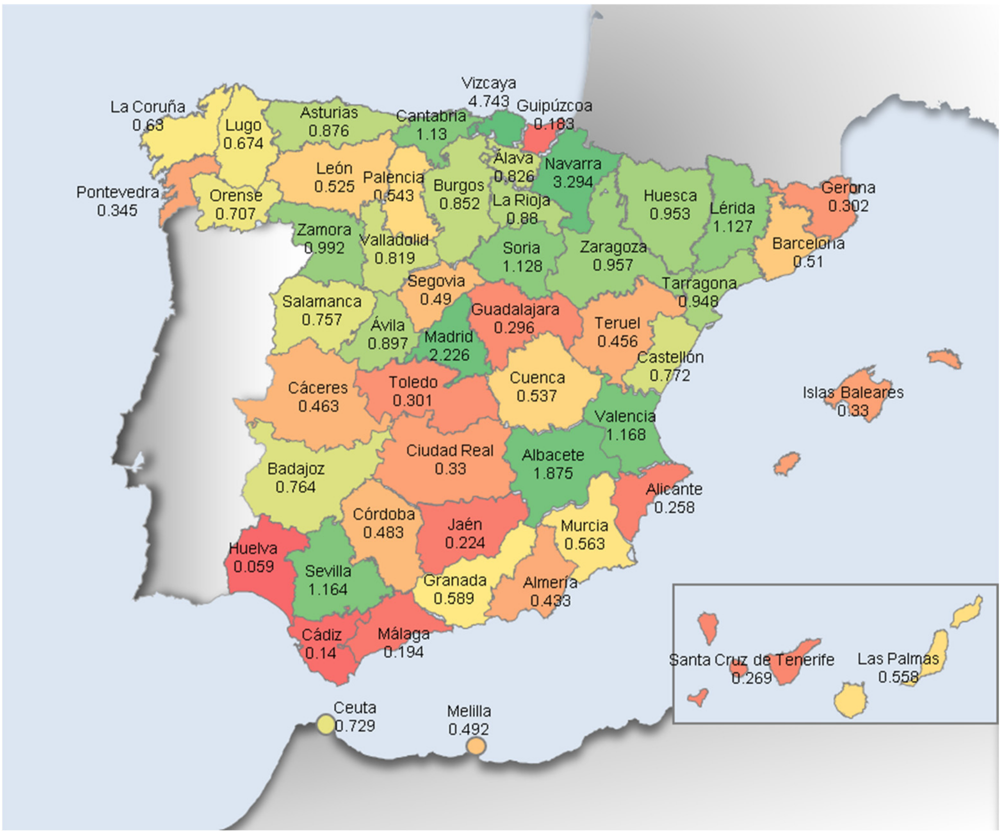


Figure 2. Degree of agglomeration of employment in the sector at the provincial level in Spain.

4.2. Model Evaluation

The model under analysis includes multidimensional constructs that, according to [82], are composed of different related dimensions that can be analyzed as a single theoretical concept. According to Van Riel, Henseler, Kemény, and Sasovova [83], a first analysis should be performed to obtain the scores of the first-order latent variables, which will be used in the subsequent analysis to model the second-order constructs. PLS is an effective tool for process [84]. Ringle, Sarstedt, and Straub [85] state that this two-stage process, commonly used in social science research, allows the second-order construct to be established in an endogenous way within the structural model.

The results obtained after evaluating the research model using PLS-SEM, which, according to Hair et al. [77], should be carried out in two stages, the first corresponding to the measurement model and the second to the structural model, which are presented below. The final models, both saturated and estimated, present a good fit, as they have a standardized root mean square residual [SRMSR] value of 0.057 < 0.08 [86].

4.2.1. Evaluation of the Formative and Reflective Measurement Models

When evaluating measurement models, different criteria must be followed depending on the type of construct involved, formative or reflective [77]. For the evaluation of the formative model (degree of sector agglomeration), a single item representing the essence of the latent variable that formative indicators seek to measure is used [87]. In this first step, which is also called "redundancy analysis" [88] and determines the convergent validity of the model, the degree of correlation between the different measures of the same construct is assessed by using different indicators. For this, the formative latent variable is used as an exogenous variable, which acts as a predictor of another endogenous construct that uses other indicators of a reflective nature.

Although, generally, the use of individual indicators is not recommended when using the PLS technique, in the case of redundancy analysis it is appropriate, since its objective is not to capture the total content of the construct but simply its fundamental elements, to have a standard of comparison [77].

Thus, this item, called "PSecGDP", indicates the percentage share of the sector under study of the GDP at the provincial level (For its calculation, secondary data obtained from the SABI database and the National Statistics Institute (INE) are used). According to Hair et al. [77], the value of the path coefficient between the two constructs should be greater than 0.7 and the value of R^2 greater than 0.5. The path coefficient between both formative and reflective indicators takes the value 0.916 > 0.8, and the R^2 amounts to 0.839 > 0.5, which means that the formative measurement model meets the convergent validity criterion.

The degree of collinearity of the formative indicators is significantly lower than the critical values set, as the VIF value amounts to 1.192 < 3 [89]. Finally, the significance and relevance of the formative indicators are assessed.

After running the bootstrapping process, in full mode and 5,000 random subsamples, it was found that both the weights and the external loadings of the formative indicators have significantly different values from zero, both in relative terms (External weights: L1 = 0.583 (Employment agglomeration coefficient); L2 = 0.612 (Agglomeration coefficient of the companies)) and in absolute terms (External loadings: L1 = 0.828; L2 = 0.846), which indicates that their contribution to the construct is high.

To evaluate the reflective model, internal consistency and convergent and discriminant validity must be analyzed [77]. According to these authors, in the first case, three methods are used: Cronbach's alpha (Tends to underestimate internal consistency reliability) (α), composite reliability (Tends to overestimate internal consistency reliability) (ρc) and Dijkstra–Henseler's rho (It is considered a measure of consistent reliability) (ρA).

As can be seen in Table 4, all values are significantly higher than 0.7 [77,88,90]. To confirm convergent validity, the measurement is performed by assessing the reliability of the indicators, that is, the size of the external loadings (λ) and the average variance extracted

(AVE), which refers to the total mean value of the loadings of the indicators belonging to the same construct squared [77]. Furthermore, it is observed that the value of the external loadings is greater than 0.707, and the AVE > 0.5, so this criterion is also met [77,91].

Table 4. Assessment of internal consistency and convergent validity.

Variables	Cronbach's Alpha	Rho_A	Composite Reliability	Average Variance Extracted
Association	1 indicator	1 indicator	1 indicator	1 indicator
Cooperation	0.885	0.885	0.913	0.638
I.P.	0.847	0.851	0.897	0.686
External Loads (λ)				
	Cooperation		Innovative Performance	
COOP customers	0.859			
COOP competitors	0.787			
COOP Tech. centers	0.713			
COOP others	0.756			
COOP suppliers	0.828			
COOP universities	0.841			
I.P. management			0.810	
I.P. marketing			0.786	
I.P. process			0.857	
I.P. product			0.858	

Note: COOP: Cooperation. Tech.: Technology. I.P.: Innovative performance.

Traditionally, two methods are used: cross-loading analysis and the Fornell and Larcker method. Although both criteria are fulfilled, according to [91], these methods have certain shortcomings that affect the detection of discriminant validity problems. These authors determine that the heterotrait–monotrait ratio (HTMT) is a more effective tool for this purpose.

According to Kline [92], the value of the HTMT ratio should be less than 0.85. Table 5 shows that the model largely meets this requirement.

Table 5. Evaluation of discriminant validity.

Heterotrait–Monotrait Ratio (HTMT)			
	Association	Cooperation	I.P.
Association			
Cooperation	0.631		
I.P.	0.522	0.744	

Note: I.P.: Innovative performance.

4.2.2. Evaluation of the Structural Model

The evaluation of the structural model allows us to determine the predictive capacity of the model and the type of relationships existing between the different latent variables that compose it and, consequently, to test the hypotheses put forward in the theoretical framework.

To this end, according to Hair et al. [77] the following elements must be analyzed: the significance level and relevance of the relationships, the value of the coefficients of determination (R^2), collinearity, effect size f^2, and predictive relevance (Q^2).

Figure 3 shows the nomogram, where the path coefficients obtained by running the bootstrapping process in full mode and 5000 random subsamples can be observed. Tables 6 and 7 show data corresponding to the direct and indirect effects, respectively.

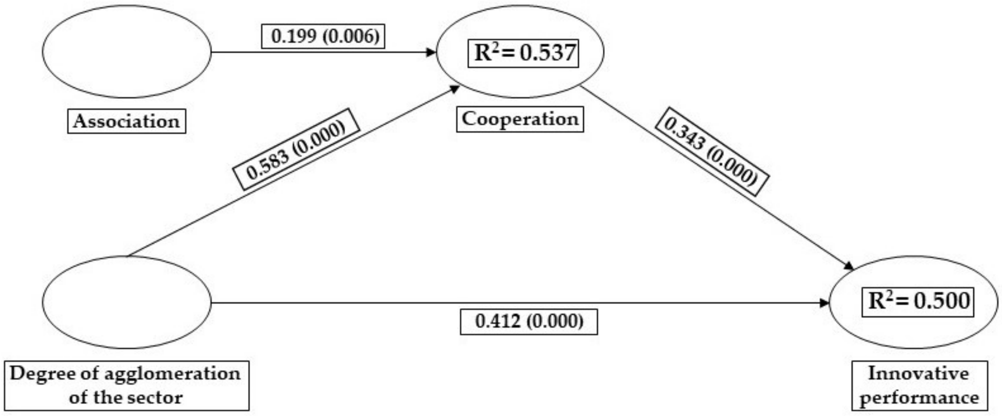


Figure 3. Path coefficients and significance levels of the proposed model.

Table 6. Summary of direct effects.

Structural Path	Coef. (β)	S.D.	*p*-Values	t0.005. 4999	99% C.I.	Results
D.A.S. -> Cooperation	0.583 **	0.066	0.000	8.808	[0.426–0.739]	
D.A.S. -> I.P.	0.412 **	0.081	0.000	4.991	[0.211–0.596]	H1 (+) ✓
Association -> Cooperation	0.199 **	0.076	0.006	2.640	[0.017–0.363]	H2 (+) ✓
Cooperation -> I.P.	0.343 **	0.094	0.000	3.646	[0.124–0.558]	

Note: C.I.: Confidence interval. D.A.S.: Degree of agglomeration of the sector. I.P.: Innovative performance. Coef.: Coefficient. S.D.: Standard deviation. ** Statistically significant at 1%.

Table 7. Summary of indirect effects.

Total Effect of D.A.S. on I.P.		Direct Effect of D.A.S. on I.P.		Indirect Effect of D.A.S. on I.P.			Results
Coef. (β)	t0.005, 4999	Coef. (β)	t0.005, 4999	Estimate	t0.005, 4999	C.I. 99%	
0.612 **	14.241	0.412 **	4.991	0.200	3.028	[0.067–0.371]	H3 (+) ✓

Note: C.I.: Confidence interval. D.A.S.: Degree of agglomeration of the sector. I.P.: Innovative performance. Coef: Coefficient. ** Statistically significant at 1%.

When analyzing the data, it is observed that there is no collinearity, as all VIF values are less than three [89]. There is a positive and significant direct effect of the degree of industry agglomeration on the innovative performance of firms [0.412, p = 0.000]. In addition, there is a positive and significant indirect effect produced by the mediation of the variable "Cooperation" [0.200, p = 0.000]. The proposed model explains 53.7% and 50.8% of the variance of the constructs "Cooperation" and "Innovative Performance", respectively.

Furthermore, the contribution of the exogenous construct "Degree of industry agglomeration" to the R^2 value of the endogenous latent variables "Cooperation" and "Innovative Performance" (f^2) is large [0.397] and median [0.167], in this order, based on the values proposed by [93]. In turn, the contribution of the exogenous construct "Cooperation" to the R^2 value of the endogenous latent variable "Innovative Performance" is median [0.115]. The data point to the existence of a direct and positive effect of belonging to an association on the degree of cooperation of firms [0.199, p =0.006], although the contribution of the exogenous construct "Association" on the endogenous latent variable "Cooperation" is small [93].

Finally, the values of the endogenous variables' "cooperation" and "innovative performance" have Q^2 values 0.335 and 0.341, respectively, which indicates that the model has a moderate predictive relevance on the mentioned variables, in accordance with the values established by Hair, Risher, Sarstedt, and Ringle [94]. Based on these data, the three hypotheses are confirmed:

✓ **H1 (+):** *There is a positive and significant relationship between the degree of agglomeration of the sector and the innovative performance of firms.*

✓ **H2 (+):** *There is a positive and significant relationship between active membership in a business association and the degree of cooperation of firms with surrounding agents.*

✓ **H3 (+):** *The degree of cooperation of firms with surrounding agents mediates the relationship between the degree of agglomeration of the sector and the innovative performance of firms.*

5. Conclusions

This paper contributes to the existing literature on the analysis of positive externalities derived from industrial agglomeration, particularly those related to cooperation and the innovative performance of firms. The three hypotheses are confirmed, thus establishing a positive and significant relationship between the variables of the proposed model. Based on these findings, three main conclusions are established. First, the positive externalities derived from industrial agglomeration boost the innovative performance of firms. Second, cooperation between specialized entities is established as an important positive externality derived from industrial agglomeration, which has a positive effect on the innovative performance of firms. Finally, business associations foster cooperation, especially among their associates, and act as representative entities that facilitate the establishment of agreements at the superstructure level.

Collaboration with external actors in knowledge sharing and the development of collaborative innovation processes increases the chances of superior innovative performance [95]. However, firms should carefully select the partners with whom they cooperate, as this is an element that directly influences the outcomes of partnerships [96]. In this regard, belonging to a region with a high degree of agglomeration in each sector implies a high degree of specialization of the linked firms [27].

Thus, industrial agglomeration derives from the existence of specialized entities located geographically close, which translates into the availability of potentially valuable partners with which to establish cooperation agreements. In addition, business associations play an intermediary role that favors cooperation at different levels. In this context, continuous interaction with specialized industry players boosts the innovative performance of firms [97].

The results obtained in this study highlight the importance of location and cooperation as drivers of firms' innovative performance. The environment in which they are located can provide opportunities for access to potential sources of valuable resources and capabilities, especially new knowledge. Therefore, despite globalization and the accelerated development of information and communication technologies in recent decades, and especially in recent years, there are certain elements associated with geographical and cognitive proximity that favor the effective transfer of knowledge and the innovative performance of companies. For this reason, it is necessary to continue to study industrial agglomeration in depth as a tool for regional economic development and competitiveness.

In relation to the limitations of the work, it is worth highlighting the eminently external focus of the study. Thus, in future work it would be interesting to incorporate the influence of the internal factors of the companies in the study of the determinants of their innovative performance. In particular, it would be interesting to incorporate the absorptive capacity of firms, which could influence the degree to which firms benefit from collaboration with external agents [98].

Author Contributions: Conceptualization, B.M.-L. and E.S.-G.; Data curation, B.M.-L., E.S.-G. and J.M.-F.; Formal analysis, E.S.-G. and E.P.-P.; Investigation, B.M.-L., E.S.-G. and J.M.-F.; Methodology, J.M.-F. and E.P.-P.; Project administration, B.M.-L.; Resources, B.M.-L., E.S.-G. and J.M.-F.; Software, E.S.-G. and E.P.-P.; Validation, E.S.-G. and E.P.-P.; Writing—original draft, B.M.-L. and E.S.-G.; Writing—review & editing, J.M.-F. and E.P.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Concept	Items	Definition	Measurement
Cooperation	Coop1	Degree to which your company cooperates with its customers.	Likert scale (−3 = Far inferior relative to my competitors; +3 = Far superior relative to my competitors).
	Coop2	Extent to which your company cooperates with its suppliers.	
	Coop3	Degree to which your company cooperates with its competitors.	
	Coop4	Extent to which your company cooperates with universities.	
	Coop5	Extent to which your company cooperates with technology centers.	
	Coop6	Extent to which your company cooperates with other types of institutions.	
Association	Asoc1	Yes, and actively participates.	Single election.
	Asoc2	Yes, but it does NOT actively participate.	
	Asoc3	No.	
Innovative performance	DI1	Degree of novelty of our new products.	Likert scale (−3 = Far inferior relative to my competitors; +3 = Far superior relative to my competitors).
	DI2	Use of the latest technological innovations in the new products developed by my company.	
	DI3	Speed of new product development.	
	DI4	Number of new products introduced by my company in the market.	
	DI5	Number of our new products that are new to the market (they are the first to be launched on the market).	
	DI6	Level of technological competitiveness of my company.	
	DI7	Speed with which the latest technological innovations are adopted in our processes.	
	DI8	Degree to which the technology used in our processes is up to date or new.	
	DI9	Pace of updating our processes, techniques, and technologies.	
	DI10	In my company, the development of new distribution channels for products and services is an ongoing process.	Likert scale (−3 = Strongly disagree; +3 = Strongly agree).
	DI11	In my company, customer suggestions or complaints are handled with urgency and attention.	
	DI12	My company develops better marketing innovations than its competitors.	
	DI13	My company constantly emphasizes and introduces management innovations.	

Concept	Items	Definition	Measurement
Size	TM	Company size.	Number of employees as of 31 December 2020
Age	ANT	Seniority of the company.	Years elapsed between the date of incorporation and fiscal year 2020

References

1. Kijkasiwat, P.; Phuensane, P. Innovation and firm performance: The moderating and mediating roles of firm size and small and medium enterprise finance. *J. Risk Financ. Manag.* **2020**, *13*, 97. [CrossRef]
2. Lee, D.S. Towards urban resilience through inter-city networks of co-invention: A case study of US cities. *Sustainability* **2018**, *10*, 289. [CrossRef]
3. Gherghina, Ș.C.; Botezatu, M.A.; Hosszu, A.; Simionescu, L.N. Small and Medium-Sized Enterprises (SMEs): The Engine of Economic Growth through Investments and Innovation. *Sustainability* **2020**, *12*, 347. [CrossRef]
4. Lee, R.; Lee, J.H.; Garrett, T.C. Synergy effects of innovation on firm performance. *J. Bus. Res.* **2019**, *99*, 507–515. [CrossRef]
5. Ramadani, V.; Hisrich, R.D.; Abazi-Alili, H.; Dana, L.P.; Panthi, L.; Abazi-Bexheti, L. Product innovation and firm performance in transition economies: A multi-stage estimation approach. *Technol. Forecast. Soc. Chang.* **2019**, *140*, 271–280. [CrossRef]
6. Lin, W.L.; Yip, N.; Ho, J.A.; Sambasivan, M. The adoption of technological innovations in a B2B context and its impact on firm performance: An ethical leadership perspective. *Ind. Mark. Manag.* **2020**, *89*, 61–71. [CrossRef]
7. Klerkx, L.; Proctor, A. Beyond fragmentation and disconnect: Networks for knowledge exchange in the English land management advisory system. *Land Use policy* **2013**, *30*, 13–24. [CrossRef]
8. Pyburn, R.; Woodhill, J. *Dynamics of Rural Innovation—A Primer for Emerging Professionals*, 1st ed.; LM Publishers: Arnhem, The Netherlands, 2014.
9. Alexy, O.; George, G.; Salter, A.J. Cui bono? The selective revealing of knowledge and its implications for innovative activity. *Acad. Manag. Rev.* **2013**, *38*, 270–291. [CrossRef]
10. Tranekjer, T.L.; Knudsen, M.P. The (unknown) providers to other firms' new product development: What's in it for them? *J. Prod. Innov. Manag.* **2012**, *29*, 986–999. [CrossRef]
11. Wang, C.; Hu, Q. Knowledge sharing in supply chain networks: Effects of collaborative innovation activities and capability on innovation performance. *Technovation* **2020**, *94*, 102010. [CrossRef]
12. Kim, N.; Shim, C. Social capital, knowledge sharing and innovation of small-and medium-sized enterprises in a tourism cluster. *Int. J. Contemp. Hosp. Manag.* **2018**, *30*, 2417–2437. [CrossRef]
13. Le, P.B.; Lei, H. The effects of innovation speed and quality on differentiation and low-cost competitive advantage. *Chin. Manag. Stud.* **2018**, *12*, 305–322. [CrossRef]
14. Chen, C.J.; Hsiao, Y.C.; Chu, M.A. Transfer mechanisms and knowledge transfer: The cooperative competency perspective. *J. Bus. Res.* **2014**, *67*, 2531–2541. [CrossRef]
15. Wang, R.H.; Lv, Y.B.; Duan, M. Evolutionary game of inter-firm knowledge sharing in innovation cluster. *Evol. Syst.* **2017**, *8*, 121–133. [CrossRef]
16. Porter, M.E. *The Competitive Advantage of Nations*, 1st ed.; The Free Press: New York, NY, USA, 1990.
17. Dalziel, M. The impact of industry associations: Evidence from Statistics Canada data. *Innovation* **2006**, *8*, 296–306. [CrossRef]
18. Howells, J. Intermediation and the role of intermediaries in innovation. *Res. Policy* **2006**, *35*, 715–728. [CrossRef]
19. Mejía-Villa, A.; Tanco, J.A.A.; San Martín, E.S. *Analysis of the Absorptive Capacity Process in Business Associations as Innovation Intermediaries*; Workingpaper; University of Navarra: Navarra, Spain, 2017.
20. De Groot, H.L.; Poot, J.; Smit, M.J. Agglomeration externalities, innovation and regional growth: Theoretical perspectives and meta-analysis. In *Handbook of Regional Growth and Development Theories*, 1st ed.; Capello, R., Nijkamp, P., Eds.; Edward Elgar: Cheltenham, UK, 2009; pp. 256–281. [CrossRef]
21. Baldwin, C.; Von Hippel, E. Modeling a paradigm shift: From producer innovation to user and open collaborative innovation. *Organ. Sci.* **2011**, *22*, 1399–1417. [CrossRef]
22. Laursen, K.; Salter, A. Open for innovation: The role of openness in explaining innovation performance among UK manufacturing firms. *Strateg. Manag. J.* **2006**, *27*, 131–150. [CrossRef]
23. Parra-Requena, G.; Molina-morales, F.X.; García-Villaverde, P.M. The mediating effect of cognitive social capital on knowledge acquisition in clustered firms. *Growth Chang.* **2010**, *41*, 59–84. [CrossRef]
24. Mejía-Villa, A.; Recalde, M.; Alfaro, J.A.; Gutierrez, E. Business associations as collaborative innovation communities: Development of a theoretical model. In Proceedings of the 23rd Innovation and Product Development Management Conference (IPDMC), Glasgow, UK, 12–14 June 2016; European Institute for Advanced Studies in Management (EIASM): Brussel, Belgium, 2016.
25. Li, D.; Wei, Y.D.; Miao, C.; Wu, Y.; Xiao, W. Innovation, Network Capabilities, and Sustainable Development of Regional Economies in China. *Sustainability* **2019**, *11*, 4770. [CrossRef]

26. Delgado, M.; Porter, M.E.; Stern, S. Clusters and entrepreneurship. *J. Econ. Geogr.* **2010**, *10*, 495–518. [CrossRef]
27. Resbeut, M.; Gugler, P.; Charoen, D. Spatial agglomeration and specialization in emerging markets: Economic efficiency of clusters in Thai industries. *Compet. Rev. Int. Bus. J.* **2019**, *29*, 236–252. [CrossRef]
28. Porter, M.E. Clusters and the new economics of competition. *Harv. Bus. Rev.* **1998**, *76*, 77–90.
29. Asheim, B.T.; Isaksen, A. Regional innovation systems: The integration of local 'sticky'and global 'ubiquitous' knowledge. *J. Technol. Transf.* **2002**, *27*, 77–86. [CrossRef]
30. McCann, P.; Ortega-Argilés, R. Smart specialization, regional growth and applications to European Union cohesion policy. *Reg. Stud.* **2015**, *49*, 1291–1302. [CrossRef]
31. Nonaka, I.; Konno, N. The concept of "ba": Building a foundation for knowledge creation. *Calif. Manag. Rev.* **1998**, *40*, 40–54. [CrossRef]
32. Chesbrough, H. *Open Business Models: How to Thrive in the New Innovation Landscape*, 1st ed.; Harvard Business Press: Boston, MA, USA, 2006.
33. Becerra, M.; Lunnan, R.; Huemer, L. Trustworthiness, risk, and the transfer of tacit and explicit knowledge between alliance partners. *J. Manag. Stud.* **2008**, *45*, 691–713. [CrossRef]
34. García-Peñalvo, F.J.; Colomo-Palacios, R.; Lytras, M.D. Informal learning in work environments: Training with the Social Web in the workplace. *Behav. Inform. Technol.* **2012**, *31*, 753–755. [CrossRef]
35. Zheng, W. A social capital perspective of innovation from individuals to nations: Where is empirical literature directing us? *Int. J. Manag. Rev.* **2010**, *12*, 151–183. [CrossRef]
36. Kiseleva, O.N.; Sysoeva, O.V.; Vasina, A.V.; Sysoev, V.V. Updating the Open Innovation Concept Based on Ecosystem Approach: Regional Aspects. *J. Open Innov. Technol. Mark. Complex.* **2022**, *8*, 103. [CrossRef]
37. Sun, M.; Zhang, X.; Zhang, X. The Impact of a Multilevel Innovation Network and Government Support on Innovation Performance—An Empirical Study of the Chengdu–Chongqing City Cluster. *Sustainability* **2022**, *14*, 7334. [CrossRef]
38. Krenz, P.; Basmer, S.; Buxbaum-Conradi, S.; Redlich, T.; Wulfsberg, J.P. Knowledge management in value creation networks: Establishing a new business model through the role of a knowledge-intermediary. *Procedia CIRP* **2014**, *16*, 38–43. [CrossRef]
39. De Silva, M.; Howells, J.; Meyer, M. Innovation intermediaries and collaboration: Knowledge-based practices and internal value creation. *Res. Policy* **2018**, *47*, 70–87. [CrossRef]
40. Audretsch, D.B.; Hülsbeck, M.; Lehmann, E.E. Regional competitiveness, university spillovers, and entrepreneurial activity. *Small Bus. Econ.* **2012**, *39*, 587–601. [CrossRef]
41. Icart, I.B.; Suρι, A.V. *The Government of the Human Factor*; Delta Publicaciones: Madrid, Spain, 2007.
42. Oliva, F.; Couto, M.; Santos, R.; Bresciani, S. The integration between knowledge management and dynamic capabilities in agile organizations. *Manag. Decis.* **2019**, *57*, 1960–1979. [CrossRef]
43. Matthyssens, P.; Pauwels, P.; Vandenbempt, K. Strategic flexibility, rigidity and barriers to the development of absorptive capacity in business markets: Themes and research perspectives. *Ind. Mark. Manag.* **2005**, *34*, 547–554. [CrossRef]
44. Kekezi, O.; Klaesson, J. Agglomeration and innovation of knowledge intensive business services. *Ind. Innov.* **2020**, *27*, 538–561. [CrossRef]
45. Boschma, R. Role of proximity in interaction and performance: Conceptual and empirical challenges. *Reg. Stud.* **2005**, *39*, 41–45. [CrossRef]
46. Rodríguez-Rodríguez, G.; Ballesteros, H.M.; Martínez-Cabrera, H.; Vilela, R.; Pennino, M.G.; Bellido, J.M. On the Role of Perception: Understanding Stakeholders' Collaboration in Natural Resources Management through the Evolutionary Theory of Innovation. *Sustainability* **2021**, *13*, 3564. [CrossRef]
47. Omobhude, C.; Chen, S.-H. The Roles and Measurements of Proximity in Sustained Technology Development: A Literature Review. *Sustainability* **2019**, *11*, 224. [CrossRef]
48. Alguezaui, S.; Filieri, R. Investigating the role of social capital in innovation: Sparse versus dense network. *J. Knowl. Manag.* **2010**, *14*, 891–909. [CrossRef]
49. Waples, E.P.; Friedrich, T.L. Managing creative performance: Important strategies for leaders of creative efforts. *Adv. Deve. Hum. Resour.* **2011**, *13*, 366–385. [CrossRef]
50. Parra-Requena, G.; Ruiz-Ortega, M.J.; Garcia-Villaverde, P.M. Social capital and effective innovation in industrial districts: Dual effect of absorptive capacity. *Ind. Innov.* **2013**, *20*, 157–179. [CrossRef]
51. Juhász, S.; Lengyel, B. Creation and persistence of ties in cluster knowledge networks. *J. Econ. Geogr.* **2018**, *18*, 1203–1226. [CrossRef]
52. Wang, B.; Sun, A.; Zheng, Q.; Wu, D. Spatial-temporal characteristics of green development cooperation network among belt and road initiative regions and countries. *Sustainability* **2021**, *13*, 11216. [CrossRef]
53. Argote, L.; Ren, Y. Transactive memory systems: A microfoundation of dynamic capabilities. *J. Manag. Stud.* **2012**, *49*, 1375–1382. [CrossRef]
54. Martín de Castro, G. Knowledge management and innovation in knowledge-based and high-tech industrial markets: The role of openness and absorptive capacity. *Ind. Mark. Manag.* **2015**, *47*, 143–146. [CrossRef]
55. Clauss, T.; Kesting, T. How businesses should govern knowledge-intensive collaborations with universities: An empirical investigation of university professors. *Ind. Mark. Manag.* **2017**, *62*, 185–198. [CrossRef]
56. Formichella, M. The evolution of the concept of innovation and its relationship with development. *INTA* **2005**, *1*, 1–46.
57. McEvily, B.; Marcus, A. Embedded ties and the acquisition of competitive capabilities. *Strateg. Manag. J.* **2005**, *26*, 1033–1055. [CrossRef]
58. Liu, N.; Wang, J.; Song, Y. Organization Mechanisms and Spatial Characteristics of Urban Collaborative Innovation Networks: A Case Study in Hangzhou, China. *Sustainability* **2019**, *11*, 5988. [CrossRef]
59. Vivas, C.; Gil, A.B. Impact on firms of the use of knowledge external sources: A systematic review of the literature. *J. Econ. Surv.* **2015**, *29*, 943–964. [CrossRef]

60. Fujita, M.; Krugman, P.R.; Venables, A. *The Spatial Economy: Cities, Regions, and International Trade*; MIT Press: Cambridge, MA, USA, 1999. [CrossRef]
61. De Groot, H.L.; Poot, J.; Smit, M.J. Which agglomeration externalities matter most and why. *J. Econ. Surv.* **2016**, *30*, 756–782. [CrossRef]
62. Hair, J.F.; Hult, G.T.M.; Ringle, C.; Sarstedt, M. *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*; Sage Publications: Thousand Oaks, CA, USA, 2016. [CrossRef]
63. Prajogo, D.I.; Ahmed, P.K. Relationships between innovation stimulus, innovation capacity, and innovation performance. *RandD Manag.* **2006**, *36*, 499–515. [CrossRef]
64. Škerlavaj, M.; Song, J.H.; Lee, Y. Organizational learning culture, innovative culture and innovations in South Korean firms. *Expert Syst. Appl.* **2010**, *37*, 6390–6403. [CrossRef]
65. McCann, B.T.; Folta, T.B. Location matters: Where we have been and where we might go in agglomeration research. *J. Manag.* **2008**, *34*, 532–565. [CrossRef]
66. Kukalis, S. Agglomeration economies and firm performance: The case of industry clusters. *J. Manag.* **2010**, *36*, 453–481. [CrossRef]
67. Díez-Vial, I. Geographical cluster and performance: The case of Iberian ham. *Food Policy* **2011**, *36*, 517–525. [CrossRef]
68. Boix, R.; Trullén, J. Industrial districts, innovation and I-district effect: Territory or industrial specialization? *Eur. Plan. Stud.* **2010**, *18*, 1707–1729. [CrossRef]
69. Marco-Lajara, B.; Claver-Cortés, E.; Úbeda-García, M.; Zaragoza-Sáez, P.D.C. Hotel performance and agglomeration of tourist districts. *Reg. Stud.* **2016**, *50*, 1016–1035. [CrossRef]
70. Díaz-Díaz, N.L.; de Saá Pérez, P. The interaction between external and internal knowledge sources: An open innovation view. *J. Knowl. Manag.* **2014**, *18*, 430–446. [CrossRef]
71. Marco-Lajara, B. The Cooperation between Companies in the Industrial Fabric of the Province of Alicante: An Analysis Based on the Model of Strategic Management. Ph.D. Dissertation, University of Alicante, Alicante, Spain, 2000.
72. Aguilar-Olavés, G.; Herrera, L.; Clemenza, C. Absorptive capacity: Theoretical and empirical approaches for the service sector. *Rev. Venez. Gerenc.* **2014**, *19*, 499–518. [CrossRef]
73. González, C.H.; Hurtado, A.A. Influence of absorption capacity on innovation: An empirical analysis in Colombian SMES. *Estudios Gerenc.* **2014**, *30*, 277–286.
74. Claver-Cortés, E.; Marco-Lajara, B.; Manresa-Marhuenda, E. Location in science-technology parks, dynamic capabilities and business innovation. *Ind. Econ.* **2015**, *397*, 59–71. [CrossRef]
75. Hair, J.F.; Sarstedt, M.; Pieper, T.M.; Ringle, C.M. The use of partial least squares structural equation modeling in strategic management research: A review of past practices and recommendations for future applications. *Long Range Plan.* **2012**, *45*, 320–340. [CrossRef]
76. Ringle, C.M.; Wende, S.; Becker, J.M. SmartPLS 3. Bönningstedt: SmartPLS. 2015. Available online: http://www.smartpls.com (accessed on 1 January 2021).
77. Hair, J.F.; Hult, G.T.M.; Ringle, C.M.; Sarstedt, M.; Castillo Apraiz, J.; Cepeda Carrión, G.; Roldán, J.L. *Manual de Partial Least Squares Structural Equation Modeling (Pls-Sem)*, 1st ed.; OmniaScience Scholar: Madrid, Spain, 2019. [CrossRef]
78. Roldán, J.L.; Cepeda, G. *Variance-Based Structural Equation Models: Partial Least Squares (PLS) for Researchers in Social Sciences*, 1st ed.; University of Seville: Seville, Spain, 2019.
79. Martínez, M.A.; Fierro, E.M. Application of the PLS-SEM technique in knowledge management: A practical technical approach. RIDE. *Ibero-Am. J. Educ. Res. Dev.* **2018**, *8*, 130–164. [CrossRef]
80. Henseler, J. Partial least squares path modeling: Quo vadis? *Q. Quant.* **2018**, *52*, 1–8. [CrossRef]
81. Henseler, J.; Hubona, G.; Ray, P.A. Using PLS path modeling in new technology research: Updated guidelines. *Ind. Manag. Data* **2016**, *116*, 2–20. [CrossRef]
82. Edwards, J.R. Multidimensional Constructs in Organizational Behavior Research: An Integrative Analytical Framework. *Organ. Res. Methods* **2001**, *4*, 144–192. [CrossRef]
83. Van Riel, A.C.; Henseler, J.; Kemény, I.; Sasovova, Z. Estimating hierarchical constructs using consistent partial least squares. *Ind. Manag. Data Syst.* **2017**, *117*, 459–477. [CrossRef]
84. Sarstedt, M.; Hair, J.F.; Ringle, C.M.; Thiele, K.O.; Gudergan, S.P. Estimation issues with PLS and CBSEM: Where the bias lies! *J. Bus. Res.* **2016**, *69*, 3998–4010. [CrossRef]
85. Ringle, C.M.; Sarstedt, M.; Straub, D.W. Editor's comments: A critical look at the use of PLS-SEM in "MIS Quarterly". *MIS Q.* **2012**, *36*, 3–14. [CrossRef]
86. Hu, L.T.; Bentler, P.M. Fit indices in covariance structure modeling: Sensitivity to underparameterized model misspecification. *Psychol. Methods* **1998**, *3*, 424. [CrossRef]
87. Sarstedt, M.; Wilczynski, P.; Melewar, T.C. Measuring reputation in global markets—A comparison of reputation measures' convergent and criterion validities. *J. World Bus.* **2013**, *48*, 329–339. [CrossRef]
88. Chin, W.W. The partial least squares approach to structural equation modeling. *Modern Methods Bus. Res.* **1998**, *295*, 295–336.
89. Hair, J.F.; Babin, B.J.; Anderson, R.E.; Black, W.C. *Multivariate Data Analysis*, 8th ed.; Cengage Learning: Hampshire, UK, 2019.
90. Dijkstra, T.K.; Henseler, J. Consistent partial least squares path modeling. *MIS Q.* **2015**, *39*, 297–316. [CrossRef]
91. Henseler, J.; Ringle, C.M.; Sarstedt, M. A new criterion for assessing discriminant validity in variance-based structural equation modeling. *J. Acad. Mark. Sci.* **2015**, *43*, 115–135. [CrossRef]

92. Kline, R.B. Convergence of structural equation modeling and multilevel modeling. In *The SAGE Handbook of Innovation in Social Research Methods*, 1st ed.; Malcolm, W., Vogt, W.P., Eds.; SAGE Publications: Thousand Oaks, CA, USA, 2011; pp. 562–589. [CrossRef]
93. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*; Erlbaum: Hillsdale, NJ, USA, 1988.
94. Hair, J.F.; Risher, J.J.; Sarstedt, M.; Ringle, C.M. When to use and how to report the results of PLS-SEM. *Eur. Bus. Rev.* **2019**, *31*, 2–24. [CrossRef]
95. Lazzarotti, V.; Bengtsson, L.; Manzini, R.; Pellegrini, L.; Rippa, P. Openness and innovation performance. *Eur. J. Innov. Manag.* **2017**, *20*, 463–492. [CrossRef]
96. Prashant, K.; Harbir, S. Managing strategic alliances: What do we know now, and where do we go from here? *Acad. Manag. Perspect.* **2009**, *23*, 45–62. [CrossRef]
97. Howell, A. Agglomeration, absorptive capacity and knowledge governance: Implications for public-private firm innovation in China. *Reg. Stud.* **2020**, *54*, 1069–1083. [CrossRef]
98. Najafi-Tavani, S.; Najafi-Tavani, Z.; Naudé, P.; Oghazi, P.; Zeynaloo, E. How collaborative innovation networks affect new product performance: Product innovation capability, process innovation capability, and absorptive capacity. *Ind. Mark. Manag.* **2018**, *73*, 193–205. [CrossRef]

energies

MDPI

Article

Optimizing Multi Cross-Docking Systems with a Multi-Objective Green Location Routing Problem Considering Carbon Emission and Energy Consumption

Ieva Meidute-Kavaliauskiene [1,*], Nihal Sütütemiz [2], Figen Yıldırım [3], Shahryar Ghorbani [4] and Renata Činčikaitė [1]

[1] Department of Business Technologies and Entrepreneurship, Vilnius Gediminas Technical University, Sauletekio al. 11, 10223 Vilnius, Lithuania; renata.cincikaite@vilniustech.lt
[2] Department of Management Information Systems, University of Sakarya, Sakarya 54050, Turkey; nihals@sakarya.edu.tr
[3] Department of International Trade, Istanbul Commerce University, Istanbul 34445, Turkey; figen@ticaret.edu.tr
[4] Department of Production Management, University of Sakarya, Sakarya 54050, Turkey; mg.shahryar@gmail.com
* Correspondence: ieva.meidute-kavaliaukiene@vilniustech.lt

Abstract: Cross-docking is an excellent way to reduce the space required to store goods, inventory management costs, and customer order delivery time. This paper focuses on cost optimization, scheduling incoming and outgoing trucks, and green supply chains with multiple cross-docking. The three objectives are minimizing total operating costs, truck transportation sequences, and carbon emissions within the supply chain. Since the linear programming model is an integer of zero and one and belongs to NP-hard problems, its solution time increases sharply with increasing dimensions. Therefore, the non-dominated sorting genetic algorithm-II (NSGA-II) and the multi-objective particle swarm optimization (MOPSO) were used to find near-optimal solutions to the problem. Then, these algorithms were compared with criteria such as execution time and distance from the ideal point, and the superior algorithm in each criterion was identified.

Keywords: non-dominated sorting genetic algorithm-II (NSGA-II); multi-objective particle swarm optimization (MOPSO); cross-docking

Citation: Meidute-Kavaliauskiene, I.; Sütütemiz, N.; Yıldırım, F.; Ghorbani, S.; Činčikaitė, R. Optimizing Multi Cross-Docking Systems with a Multi-Objective Green Location Routing Problem Considering Carbon Emission and Energy Consumption. *Energies* **2022**, *15*, 1530. https://doi.org/10.3390/en15041530

Academic Editors: Bernard Ziębicki and Edyta Bielińska-Dusza

Received: 21 December 2021
Accepted: 16 February 2022
Published: 18 February 2022

1. Introduction

Logistics strategy is an essential advantage for supply chain management operations that requires centralized planning and adjustment of procedures to reduce costs and increase customer satisfaction [1,2]. Classic supply chain management for transporting goods from suppliers to the distribution centre requires warehousing for storage [3] and then packaging and shipping to customers [4], according to their demand [5]. This form of supply chain management has high inventory maintenance costs and human resources costs [6,7]. In other words, there are four stages of receiving, storage, order selection, and sending in traditional warehouses [8]. Still, in the cross-dock, the storage stage, one of the main obstacles of inventory systems, is removed [9,10]. Therefore, it reduces inventory and increases customer satisfaction [11]. Cross-dock is a logistic method that distributes products directly from a supplier or factory [12]. The cross-dock method ensures timely transportation and better coordination between supply and demand [13]. In recent years, one of the issues facing the supply chain was clean production and environmental protection [5]. One of the critical issues of clean output is using supply chains that pay attention to environmental issues in all supply chain processes [14,15].

In this research, we investigate the operational cross-docking decisions that concern the optimization of short-term decisions such as CO_2 emission and energy consumption that are directly related to the transit of products from inbound trucks to outbound trucks.

We focus on the optimization of the truck to door assignment problem, which is one of the key issues in cross-docking. It attempts to find the optimal assignment for each incoming inbound or outbound truck to the appropriate inbound or outbound dock according to the cross-dock characteristics. When the problem of truck-to-door assigning is mentioned, two different questions should be answered: at which door and in which order the trucks should be docked. The first question was answered by many researchers, but the second question receives less attention and this research tries to investigate the answer to this question. The cross-docking system targets to reduce the cost of inventory holding and minimize the delivery time from suppliers to retailers in the supply chain. However, this paper addresses the cross-dock selection and optimization problem, which was first considered with the vehicle routing problem (VRP) by Maknoon and Laporte (2017), to make optimal decisions on route construction and freight consolidation cross-docks. In other words, selecting cross-docks as freight consolidation points leads to gaining economies of scale. The products are processed and transported to the customers by at least one cross-dock in the CDS problem. It has a vast application in production and retail companies and logistic service providers that handle various shipments on large networks.

Dondo and Cerda (2014) took a different approach to applying the time window so that a variable was used to determine the time window interval [16]. If there is a time window, this variable will be greater than zero for error; otherwise, it will be zero [13]. Mohtashami et al. (2015), in a study to provide and optimize a multi-objective mathematical model in the cross-dock and the entire supply chain, assumed that the supplier can also send the product directly to the customer and send it to the cross-dock [15]. On the other hand, multiple objectives, such as minimizing the total transport time of trucks, total cost, number of shipments, and model solving with NSGA-II and MOPSO with unsuccessful sorting and comparing the results of the above two algorithms, were included in their research. Mohtashami (2015) presented a new dynamic genetic algorithm based on the vehicle scheduling method in the cross-dock system to reduce the operation time. This algorithm assumed the existence of a temporary warehouse for receiving and sending goods, frequent entry and exit of trucks, and two types of chromosomes determined for incoming and outgoing trucks, providing a shorter solution for the operating time [17]. Ponboon et al., 2016, evaluated the cost structure and the impact of parameters on location issues and time windows in the distribution network. Nine scenarios of the Osaka distribution network of freight cargo with different warehouse locations were tested with two criteria, warehouse size and vehicle size. Therefore, using a large warehouse with a large vehicle will reduce costs. Warehouse features, vehicles, and shipping information were also discussed in detail [18]. Gomes et al. (2018) conducted bibliometric research in warehouse management systems from 2006 to 2016 [19].

Birim (2016) investigated the vehicle routing problem with cross-dock, considering heterogeneous vehicles with variable capacity and seeking to minimize the objective function of the total cost of transportation. The problem was solved with a simulated annealing algorithm, and the best answer is compared [20]. Yin and Chuang (2016) emphasized that we must focus on the green supply chain for sustainable development in the supply chain and pay attention to the friendly environment and business values. This paper deals with the minimum cost of green vehicle routing in transporting final products from suppliers to customers through a cross-dock with limited carbon dioxide emissions. Load management for long distances with the lowest cost and carbon dioxide emissions determine high fuel efficiency with the tabu search algorithm [21]. Wisittipanich and Hengmeechai (2017) said that one of the fundamental operational management problems is scheduling trucks in assigning them to cross-dock doors and arranging all domestic and foreign trucks for loading and unloading. This paper presents a mathematical model of integer hybrid programming for allocating and setting trucks in a multi-door cross-docking system. The purpose of this model is to minimize the total operation time. Then, a modified particle swarm algorithm is proposed and optimized with special unique designs, coding, and decoding to solve the problem of truck scheduling in a cross-docking system [16]. Zulaga et al. (2017) showed that this type of dock has results such as reducing cost time and improving management information in reverse processes. Sensitivity analysis of this model helps companies enhance their competitive position by providing flexibility concerning products, reducing the likelihood of product returns from the secondary market, and combining product returns and cross-dock costs relative to traditional warehousing [14]. Mohtashami and Najafabadi (2014) examined the reduction of operating time in the entire supply chain in their article. In the proposed model, the incoming trucks move directly towards the customers or the cross-dock in the first stage after loading the products from the suppliers. The products are unloaded in the cross-dock and loaded in the output trucks in the second stage. Then, the products are transferred to the customers [22].

Table 1 summarize the literature regarding optimizing multi cross-docking systems (MCDS) and compare the existing problems with the problem proposed in this paper.

Table 1. Summary of literature regarding MCDS and its different variants.

References	Multiple Cross-Docks	Type of Vehicle		Time Windows	Capacity in Crossdocks		Multiple Objectives	Solution Method		
		Homogeneous	Heterogeneous		Limited	Unlimited		Exact	Heuristic	Metaheuristic
[23]	*		*			*			*	
[24]	*	*			*			*	*	
[25]	*		*			*		*		
[26]		*		*		*			*	
[27]	*	*			*			*		*
[28]	*		*	*		*		*		
[29]		*				*			*	
[30]		*				*	*		*	
[31]		*				*		*		
[32]	*		*	*		*		*		
[9]	*		*	*	*			*		*
[33]	*		*	*		*	*	*		
[34]			*	*	*					*
[11]	*	*		*	*		*			*
[35]		*		*	*		*			*
Current research	*		*	*		*	*	*		*

Since cross-docks and related transportations have significant roles in increasing the efficiency of large-scale supply chain distribution networks, considering the other real-world essential factors such as reliability and pollution is attractive in designing or redesigning this network. Reliability maximization leads to customer satisfaction and earning a lot of market shares, whereas pollution minimization creates eco-friendly industries.

The research conducted was generally related to cross-dock and focused on optimizing the timing of trucks and the cost of transportation inside the dock. In this research, by considering several cross-docks and concentrating on green management with a norm time window approach for customers, issues related to out-of-cross-dock and the entire supply chain operations are also addressed. This study focuses on optimizing the cost of transporting trucks by locating the cross-dock, the sequence of transporting trucks, and the amount of carbon dioxide emissions in the environment simultaneously throughout the supply chain. In summary, the contributions of this research are described as follows.

- Developing a novel mathematical model to integrate CDS results in a comprehensive problem with a great application in industries;
- Making the problem closer to the real-world conditions by considering the effects of GHG emission in the transportation process and calculating energy consumption dependent on traffic time;
- Investigating the total cost minimization related to transportation, minimizing truck transportation sequences and carbon emissions through cross-docking simultaneously;
- Designing high-quality algorithms, including NSGA-II and MOPSO, efficiently to solve the large-sized problem.

2. Problem Statements

In this paper, three objective functions, including minimizing the total cost of operation, truck transport sequence, and carbon dioxide emissions, are examined. The proposed model also examines the relationship between (cross-dock–suppliers), (cross-dock–customers), (suppliers–customers), (suppliers–suppliers), (customers–customers), and (cross-dock–cross-dock) in terms of fuzzy scheduling with a norm time window approach for truck transport and reducing greenhouse gas emissions. The assumptions of the model are:

- All incoming and outgoing trucks are available in zero time;
- Homogeneous vehicles with different capacities;
- Considering the period of customer service of norm type (having the earliest service start time and the latest service start time);
- Existence of several cross-docks so that suppliers choose one of the docks to send the goods considering the minimum cost;
- Ability to connect suppliers, docks, and customers with each other;
- The type and number of products supplied by suppliers, as well as the type and number of customer demand, are clear and constant;
- In the transport sequence, a truck can load products from more than one supplier and unload products from more than one customer;
- One or more suppliers may meet a customer's requirements;
- The type and quantity of products transported by incoming trucks must be equal to the demands of customers.

To better understand and explain the research problem, the flow of operations in the supply chain is drawn in Figure 1. This figure considers several cross-dock distribution and transportation operation flows and several customers and suppliers. Vehicles with different capacities are also used to transport products in the supply chain.

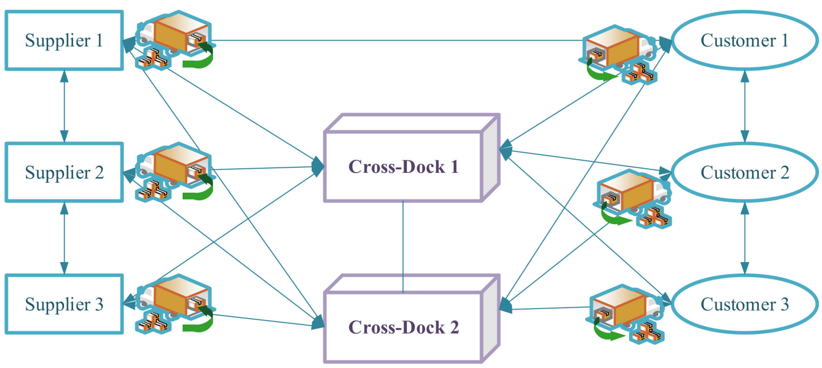


Figure 1. Operation process in the cross-dock.

After loading the products from the suppliers, the incoming trucks move directly to the customers, move to another supplier, move to one of the cross-docks, and unload the products in the cross-dock. They are then loaded onto output trucks and delivered to customers [36]. It should also be noted that a truck can load products from more than one supplier, and a truck can move to more than one customer and unload products between them. Three trucks with different capacities are used to transport the products.

2.1. Mathematical Model

The main variables and important parameters in the model and algorithms are presented in Table 2:

Table 2. Sets, parameters, and decision variables of the model.

Sets	
S	Set of suppliers (1, . . . ,S)
C	Set of customers (1, . . . ,C)
k_{in}	Set of incoming trucks (Receiving) (1, . . . ,K)
k_{out}	Set of outgoing trucks (Sending) (1, . . . ,K')
G	Set of products type (order) (1, . . . ,G)
Cd	Set of Cross-docks (1, . . . ,Z)
Parameters	
T	Transportation time
$\mathbf{A^{i}_{scG}}$	Time of entry or exit of incoming truck (i) from supplier (s), while loading the order of type (G) and moving towards the customer (c)
$\mathbf{A^{j}_{cdcG}}$	When the incoming truck (j) enters to the customer (c) from the cross-dock (cd) while loading the order of type (G)
$\mathbf{T^{i}_{scG}}$	Transportation time of incoming truck (i) from supplier (s) to customer (c) while loading the order of type (G)
$\mathbf{T^{j}_{cdcG}}$	Transport time of outgoing truck (j) from cross-dock (cd) to customer (c), while loading the order of type (G)
$\mathbf{UL^{i}_{scG}}$	Offloading time of each product type (G) from input truck (i) to customer (c)
$\mathbf{UL^{i}_{scG}}$	Offloading time of each product type (G) from output truck (j) to customer (c)
$\mathbf{D_{cG}}$	Customer order (c) of type (G) goods
$\mathbf{P_{Gs}}$	Production rate of product with type (G)
$\mathbf{w_{G}}$	Weight of product with type (G)
$\mathbf{d_{i}}$	Demand of customer (i)
$[\mathbf{e_i}, \mathbf{E_i}, \mathbf{L_i}, \mathbf{l_i}]$	Time window interval of customer (i)
$\gamma_\mathbf{i} = \mathbf{E_i} - \mathbf{A^{i}_{scG}}$	Early arrival time of incoming or outgoing truck in the time window
$\theta_\mathbf{i} = \mathbf{A^{i}_{scG}} - \mathbf{L_i}$	Incoming or outgoing truck late arrival time
$PE_{k_{out}}$	Penalty for delay or early arrival of a vehicle exiting the cross-dock (i) for the customer (c)
$PE_{k_{in}}$	Penalty for delay or early arrival of the incoming vehicle from the supplier (i) to the customer (i)
$\mathbf{w_i}$	Vehicle waiting time at the location of customer (c)
$\mathbf{o_i}$	Cost of reopening the cross-dock (i)
$\mathbf{Q^{i}}$	Capacity of incoming truck (i)
$\mathbf{Q^{j}}$	Capacity of output truck (i)
$\mathbf{d_{scd}}$	Distance between supplier (s) and cross-dock (cd)
$\mathbf{d_{sc}}$	Distance between supplier (s) and customer (c)

Table 2. *Cont.*

Sets	
$\mathbf{d_{cdc}}$	Distance between cross-dock (cd) and customer (c)
$\mathbf{C}_{k_{in}}$	The fuel conversion rate of the unloaded incoming truck to carbon dioxide
$\mathbf{C}^{/}_{k_{in}}$	The difference between the conversion rate of the fuel of an incoming truck with a load of one unit of product or more with the same truck without a load of carbon dioxide
$\mathbf{C}^{/}_{k_{out}}$	The difference between the conversion rate of the fuel of an outgoing truck with a load of one unit of product or more with the same truck without a load of carbon dioxide
$\mathbf{C}_{k_{out}}$	Conversion rate of unloaded truck fuel into CO_2
$\mathbf{g^{i}_{sc}}$	Incoming truck fuel consumption rate for travel between supplier (s) and customer (c) without load
$\mathbf{g^{i}_{scd}}$	The fuel consumption rate of incoming trucks for travel between supplier (s) and cross-dock (cd) without load
$\mathbf{g^{i}_{s_m s_n}}$	Incoming truck fuel consumption rate for travel between the source supplier (s) and the destination supplier without load
$\mathbf{g^{i}_{cd_m cd_n}}$	Incoming truck fuel consumption rate for travel between the cross-dock (cd) of origin and the cross-dock of destination without cargo
$\mathbf{g^{j}_{c_m c_n}}$	Outgoing truck fuel consumption rate for travel between origin and destination customer (c) without load
$\mathbf{g^{j}_{cdc}}$	Outgoing truck fuel consumption rate for travel between cross-dock (cd) and customer (c) without load
$\mathbf{Q}_{k_{in}}$	The difference in the fuel consumption rate of an incoming truck traveling with one product or more with the same unladen truck
$\mathbf{Q}_{k_{out}}$	The difference in the fuel consumption rate of an outgoing truck traveling with one product or more with the same unladen truck
$\mathbf{f_{scdG}}$	The number of product types (G) the truck carries between supplier (s) and cross-dock (cd)
$\mathbf{f_{scG}}$	The number of product types (G) the truck carries between supplier (s) and the customer (c)
$\mathbf{f_{cdcG}}$	The number of product types (G) the truck carries between cross-dock (cd) and customer (c)
$\mathbf{f_{s_m s_n G}}$	The number of product types (G) the truck carries between source supplier and destination supplier
$\mathbf{f_{c_m c_n G}}$	The number of product types (G) the truck carries between source customer and destination customer
$\mathbf{f_{cd_m cd_n G}}$	The number of product types (G) the truck carries between source cross-dock and destination cross-dock
E	Big number
Variables	
$\mathbf{q_{Gs}}$	The number of product types (G) that are loaded from the supplier (s) into the input truck (i)
$\mathbf{q_{Gcd}}$	The number of product types (G) that are loaded from the cross-dock (cd) into the output truck (j)
$\mathbf{q_{Gc}}$	The number of product types (G) that are unloaded from the incoming truck (i) at the customer's location
$\mathbf{q}_{\mathbf{Gs}_n}$	The number of product types (G) that are unloaded from the input truck (i) at the destination supplier s_n
$\mathbf{q_{Gcd_n}}$	The number of product types (G) that are unloaded from the output truck (j) at the destination cd_n
$\mathbf{X^{i}_{cdsG}}$	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ cross-dock\ \mathrm{cd}\ to\ supplier\ \mathrm{S}\ while\ loading\ the\ order\ of\ type\ \mathrm{G} \\ 0 & otherwise \end{cases}$
$\mathbf{X^{i}_{s_m s_n G}}$	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ supplier\ \mathrm{Sm}\ to\ destination\ Supplier\ \mathrm{Sn}\ while\ loading\ the\ order\ of\ type\ \mathrm{G} \\ 0 & otherwise \end{cases}$
$\mathbf{X^{i}_{scdG}}$	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ supplier\ \mathrm{S}\ to\ cross-dock\ \mathrm{cd}\ while\ loading\ order\ of\ type\ \mathrm{G} \\ 0 & otherwise \end{cases}$
$\mathbf{X^{i}_{scG}}$	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ supplier\ \mathrm{S}\ to\ customer\ \mathrm{C}\ while\ loading\ the\ order\ of\ type\ \mathrm{G} \\ 0 & otherwise \end{cases}$

Table 2. *Cont.*

Sets	
$X^{i}_{c_m c_n G}$	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ customer\ \mathrm{Cm}\ to\ destination\ customer\ \mathrm{Cn}\ while\ loading\ the\ order\ of\ type\ \mathrm{G} \\ 0 & otherwise \end{cases}$
X^{j}_{cdcG}	$\begin{cases} 1 & If\ outgoing\ truck\ \mathrm{j}\ moves\ from\ cross-dock\ \mathrm{cd}\ to\ customer\ \mathrm{C}\ while\ loading\ the\ order\ of\ type\ \mathrm{G} \\ 0 & otherwise \end{cases}$
X^{i}_{ccdG}	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ customer\ \mathrm{C}\ to\ cross-dock\ \mathrm{cd}\ while\ offloading\ type\ \mathrm{G}\ order \\ 0 & otherwise \end{cases}$
X^{j}_{ccdG}	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{j}\ moves\ from\ customer\ \mathrm{C}\ to\ cross-dock\ cd\ while\ offloading\ type\ \mathrm{G}\ order \\ 0 & otherwise \end{cases}$
$X^{i}_{cd_m cd_n G}$	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ source\ cross-dock\ \mathrm{cdm}\ to\ destination\ cross-dock\ cdn\ while\ loading\ type\ \mathrm{G}\ order \\ 0 & otherwise \end{cases}$
F_{cdc}	$\begin{cases} 1 & \mathrm{i}f\ \mathrm{customer}\ demand\ \mathrm{i}\ is\ met\ from\ cross-dock\ \mathrm{i} \\ 0 & otherwise \end{cases}$
y_i	$\begin{cases} 1 & if\ cross-dock\ i\ is\ selected \\ 0 & otherwise \end{cases}$
P_{ij}	$\begin{cases} 1 & if\ input\ truck\ \mathrm{i}\ precedes\ to\ input\ truck\ \mathrm{j} \\ 0 & otherwise \end{cases}$
$q_{g_1 g_2}$	$\begin{cases} 1 & if\ input\ truck\ g_1\ precedes\ to\ input\ truck\ g_2 \\ 0 & otherwise \end{cases}$
X^{i}_{scd}	$\begin{cases} 1 & If\ incoming\ truck\ i\ moves\ from\ supplier\ \mathrm{S}\ to\ cross-dock\ cd\ while\ offloading\ type\ \mathrm{G}\ order \\ 0 & otherwise \end{cases}$
X^{i}_{sc}	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ supplier\ \mathrm{S}\ to\ customer\ \mathrm{C}\ while\ offloading\ type\ \mathrm{G}\ order \\ 0 & otherwise \end{cases}$
X^{j}_{cdc}	$\begin{cases} 1 & If\ outgoing\ truck\ \mathrm{j}\ moves\ from\ cross-dock\ \mathrm{cd}\ to\ customer\ \mathrm{C}\ while\ offloading\ type\ \mathrm{G}\ order \\ 0 & otherwise \end{cases}$
$X^{i}_{c_m c_n}$	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ source\ customer\ \mathrm{Cm}\ to\ destination\ customer\ \mathrm{Cn}\ while\ offloading\ type\ \mathrm{G}\ order \\ 0 & otherwise \end{cases}$
$X^{i}_{s_m s_n G}$	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ source\ supplier\ \mathrm{Sm}\ to\ destination\ Supplier\ \mathrm{Sn}\ while\ loading\ type\ G\ order \\ 0 & otherwise \end{cases}$
$X^{i}_{s_m s_n}$	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ source\ supplier\ \mathrm{Sm}\ to\ destination\ Supplier\ \mathrm{Sn}\ while\ offloading\ type\ \mathrm{G}\ order \\ 0 & otherwise \end{cases}$
$X^{i}_{cd_m cd_n}$	$\begin{cases} 1 & If\ incoming\ truck\ \mathrm{i}\ moves\ from\ source\ cross-dock\ \mathrm{cdm}\ to\ destination\ cross-dock\ cdn\ while\ offloading\ type\ \mathrm{G}\ order \\ 0 & otherwise \end{cases}$

The first objective function minimizes the total cost of operations within the supply chain (including transportation, fuel, delay, shortage, holding, and opening costs). The second objective function minimizes the truck transport sequence between suppliers, cross-docks, and customers, and the third objective function minimizes CO_2 emissions from trucks throughout the system.

$$
\begin{aligned}
\text{Min } Z_1 \quad = & \Bigg[\Bigg(\sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G}(C^{i}_{scdG}+C^{i}_{sGcd})*X^{i}_{scdG}\Bigg) \\
& +\Bigg(\sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G}C^{i}_{scG}*X^{i}_{scG}\Bigg) \\
& +\Bigg(\sum_{i\in k_{in}=1}^{K}\sum_{s=1}^{S}\sum_{i\in G}^{G}C^{i}_{s_m s_n G}*X^{i}_{s_m s_n G}\Bigg) \\
& +\Bigg(\sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G}(C^{i}_{cdsG}*X^{i}_{cdsG}\Bigg) \\
& +\Bigg(\sum_{i\in G=1}^{G}\sum_{i\in c=1}^{C}\sum_{i\in k_{in}}^{K}C^{i}_{c_m c_n G}*X^{i}_{c_m c_n G}\Bigg) \\
& +\Bigg(\sum_{j\in k_{out}=1}^{K}\sum_{i\in cd=1}^{Z}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G}(C^{j}_{cdcG}*X^{j}_{cdcG}\Bigg) \\
& \Bigg(\sum_{j\in K_{in}=1}^{K}\sum_{i\in\ i\in cd=1}^{Z}\sum_{i\in G=1}^{G}C^{i}_{cd_m cd_n G}*X^{i}_{cd_m cd_n G}\Bigg) \\
& +\Bigg(\sum_{j\in K_{out}=1}^{K}\sum_{i\in\ c=1}^{C}\sum_{i\in G=1}^{G}C^{j}_{c_m c_n G}*X^{j}_{c_m c_n G}\Bigg) \\
& +\Bigg(\sum_{j\in K_{out}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G}c^{j}_{ccdG}*X^{j}_{CCdG}\Bigg) \\
& +\Bigg(\sum_{j\in K_{in}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in s=1}^{S}\sum_{i\in G=1}^{G}c^{i}_{csG}*X^{i}_{CsG}\Bigg) \\
& +(\sum_{i\in cd=1}^{Z}O_i y_i+\sum_{i\in s=1}^{S}\sum_{i\in I=1}^{I}\sum_{i\in G=1}^{G}F_i*X^{i}_{scdG})+[\sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G}PE_{k_{in}}*(\gamma_i+\theta_i)*X^{i}_{scG}\Big] \\
& +[\sum_{j\in K_{out}=1}^{K}\sum_{i\in I=1}^{I}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G}PE_{k_{OUT}}*(\gamma_i+\theta_i)*X^{j}_{cdcG}]
\end{aligned}
\tag{1}
$$

$$
\text{Min } Z_2 = F = \sum_{i\in s=1}^{S}\sum_{i\in c=1}^{C}\sum_{i\in cd}^{Z}\sum_{i\in k_{in}=1}^{K}\sum_{j\in k_{out}}^{K}\sum_{i\in G=1}^{G}X^{i}_{scG}+X^{i}_{scdG}+X^{i}_{s_m s_n G}+X^{i}_{csG}+X^{i}_{cdsG}+X^{j}_{cdcG}+X^{j}_{c_m c_n G}+X^{j}_{ccdG} \tag{2}
$$

$$
\begin{aligned}
\text{Min } Z_3 \quad = & \Bigg[\Big[\Bigg(\sum_{i\in s=1}^{S}\sum_{i\in cd=1}^{Z}\sum_{i\in k_{in}=1}^{K}C_{k_{in}}*g^{i}_{scd}*d_{scd}*X^{i}_{scd}\Bigg) \\
& +(\sum_{i\in s=1}^{S}\sum_{i\in s=1}^{S}\sum_{i\in G=1}^{G}\sum_{i\epsilon k_{in}}^{K}C^{/}_{k_{in}}*Q_{k_{in}}*f_{scdG}*W_G*d_{SCdG}*X^{i}_{scdG})]+[(\sum_{i\in k_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\epsilon c=1}^{C}C_{k_{in}}*g^{i}_{sc}*d_{sc}*X^{i}_{sc}) \\
& +(\sum_{i\in s=1}^{S}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G}\sum_{i\epsilon k_{in}}^{K}C^{/}_{k_{in}}*Q_{k_{in}}*f_{scG}*W_G*d_{SCG}*X^{i}_{scG})]+[(\sum_{i\in k_{in}=1}^{K}\sum_{i\in s=1}^{S}C_{k_{in}}*g^{i}_{s_m s_n}*d_{s_m s_n}*X^{i}_{s_m s_n}) \\
& +(\sum_{i\in k_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in G=1}^{G}C^{/}_{k_{in}}*Q_{k_{in}}*f_{s_m s_n G}*W_G*d_{s_m s_n G}*X^{i}_{s_m s_n G})]+[(\sum_{i\in k_{in}=1}^{K}\sum_{i\in cd=1}^{Z}C_{k_{in}}*g^{i}_{cd_m cd_n}*d_{cd_m cd_n}*X^{i}_{cd_m cd_n}) \\
& +(\sum_{i\in k_{in}=1}^{K}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G}C^{/}_{k_{in}}*Q_{k_{in}}*f_{cd_m cd_n G}*W_G*d_{cd_m cd_n G})*X^{i}_{cd_m cd_n G}]+[(\sum_{i\in cd=1}^{Z}\sum_{i\in c=1}^{C}\sum_{i\in k_{out}=1}^{K}C_{k_{out}}*g^{j}_{cdc}*d_{cdc}*X^{j}_{cdc}) \\
& +(\sum_{i\in cd=1}^{Z}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G}\sum_{i\epsilon k_{out}}^{K}C^{/}_{k_{out}}*Q_{k_{out}}*f_{cdcG}*W_G*d_{CdcG}*X^{j}_{cdcG})]+[(\sum_{i\in k_{out}=1}^{K}\sum_{i\in c=1}^{C}C_{k_{out}}*g^{j}_{c_m c_n}*d_{c_m c_n}*X^{j}_{c_m c_n}) \\
& +(\sum_{i\in k_{out}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G}C^{/}_{k_{out}}*Q_{k_{OUT}}*f_{c_m c_n G}*W_G*d_{c_m c_n G}*X^{j}_{c_m c_n G})]\Bigg]
\end{aligned}
\tag{3}
$$

S.t:

$$\sum_{i\in k_{in}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in s=1}^{S}\sum_{i\in G=1}^{G} q_{Gs} * X_{scG}^{i} = D_{cG} \tag{4}$$

$$\sum_{i\in cd=1}^{Z}\sum_{j\in k_{out}=1}^{K}\sum_{i\in C=1}^{C}\sum_{i\in G=1}^{G} q_{Gcd} * X_{cdcG}^{j} + \sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G} q_{Gs} * X_{scG}^{i} = P_{Gs} \tag{5}$$

$$\sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G} X_{scG}^{i} \geq 1 \tag{6}$$

$$X_{cdsG}^{i} = \sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in G=1}^{G} x_{s_m s_n G}^{i} + \sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G} X_{scdG}^{i} + \sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G} X_{scG}^{i} \tag{7}$$

$$X_{s_m s_n G}^{i} = \sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in G=1}^{G} x_{s_n s_m G}^{i} + \sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G} X_{s_n cdG}^{i} + \sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G} X_{scG}^{i} \tag{8}$$

$$X_{cdcG}^{j} = \sum_{j\in k_{out}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G} X_{c_m c_n G}^{j} + \sum_{i\in k_{out}}^{K}\sum_{i\in c=1}^{C}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G} X_{ccdG}^{j} \tag{9}$$

$$X_{c_m c_n G}^{i} = \sum_{i\in K_{in}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G} X_{c_n c_m G}^{i} + \sum_{i\in K_{in}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in cd=1}^{Z}\sum_{i=G=1}^{G} X_{ccdG}^{i} \tag{10}$$

$$X_{c_m c_n G}^{j} = \sum_{j\in k_{out=1}}^{K}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G} X_{c_n c_m G}^{j} + \sum_{j\in k_{out}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G} X_{ccdG}^{j} + \sum_{j\in k_{out}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G} X_{cd_m cd_n G}^{j} \tag{11}$$

$$X_{scG}^{i} = \sum_{i\in K_{in}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in G=1}^{G} X_{c_m c_n G}^{i} + \sum_{i\in K_{in}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G} X_{ccdG}^{i} \tag{12}$$

$$\sum_{i\in K_{in}=1}^{K}\sum_{i\in s=1}^{S}\sum_{i\in cd=1}^{Z}\sum_{i\in G}^{G} q_{Gs} * X_{scdG}^{i} = \sum_{i\in K_{in}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G} q_{Gcd} * X_{cdcG}^{j} \tag{13}$$

$$\sum_{i\in s=1}^{S}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G} X_{scdG}^{i} * q_{Gs} \leq Q^{i} \tag{14}$$

$$\sum_{i\in c=1}^{C}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G} X_{cdcG}^{j} * q_{Gcd} \leq Q^{j} \tag{15}$$

$$\sum_{i\in s=1}^{S}\sum_{i\in C=1}^{C}\sum_{i\in G=1}^{G} \left(A_{scG}^{i} + T_{scG}^{i} + UL_{scG}^{i} + w_{i}\right) * X_{scG}^{i} \leq A_{csG}^{i} \tag{16}$$

$$\sum_{i\in cd=1}^{Z}\sum_{i\in C=1}^{C}\sum_{i\in G=1}^{G} \left(A_{cdcG}^{j} + T_{cdcG}^{j} + UL_{cdcG}^{j} + w_{i}\right) * X_{cdcG}^{j} \leq A_{csG}^{i} \tag{17}$$

$$\sum_{j\in K_{out}=1}^{K}\sum_{i\in c=1}^{C}\sum_{i\in cd=1}^{Z}\sum_{i\in G=1}^{G} X_{cdcG}^{j} + X_{CCdG}^{j} \leq 1 + F_{cdc} \tag{18}$$

$$\sum_{i\in k_{in=1}}^{K}\sum_{i\in s=1}^{S}\sum_{i\in cd=1}^{Z}\sum_{i\in G}^{G} X_{scdG}^{i} \leq y_{i} \tag{19}$$

$$\gamma_{i} \geq E_{i} - A_{scG}^{i} \tag{20}$$

$$\theta_{i} \geq A_{scG}^{i} - L_{i} \tag{21}$$

$$\left(X_{cdsG}^{i}, X_{s_m s_n G}^{i}, X_{scdG}^{i}, X_{scG}^{i}, X_{c_m c_n G}^{i}, X_{cdcG}^{j}, X_{c_m c_n G}^{j}, X_{ccdG}^{i}, X_{ccdG}^{j}, X_{cd_m cd_n G}^{j}, y_{i}\right) \in \{0, 1\}, \tag{22}$$

$$\left(X^{i}_{cds}, X^{i}_{s_m s_n}, X^{i}_{scd}, X^{i}_{sc}, X^{i}_{c_m c_n}, X^{j}_{cdc}, X^{j}_{c_m c_n}, X^{i}_{ccd}, X^{j}_{ccd}, X^{j}_{cd_m cd_n}, F_{cdc}\right) \in \{0, 1\} \quad (23)$$

$$I = 1, 2, 3, \ldots, I,\ c = 1, 2, 3, \ldots, C\ ,\ G = 1, 2, 3, \ldots, G\ j = 1,\ 2,\ 3,\ \ldots,\ J \quad (24)$$

$$\text{All variables} \geq 0,\ \forall\, i, s, c \textit{ and } h \quad (25)$$

2.2. Description of Objective Functions and Constraints

The first objective function minimizes the cost of transporting vehicles throughout the system. The second objective function minimizes the transport sequence of trucks throughout the system. The objective is utilized to sequence inbound and outbound trucks to minimize the makespan. The third objective function minimizes the amount of carbon dioxide emitted from vehicles throughout the system. Each route between origin and destination has two sections. In the first part, the truck is unloaded, and in the second part, the truck is loaded.

Constraint (1) ensures that the total number of units of type G order product loaded from the supplier (s) in the truck (i) is precisely equal to the number of units of type (h) order product that the customer (c) needs. Constraint (2) ensures that the total number of order types (h) that are loaded from the supplier (s) in the entry truck (i) and move to the customer (c), as well as the total number of order types (h) that are loaded from the cross-docks (cd) in the output truck (j), are loaded and transferred toward the customer (c) and are exactly equal to the sum of the number of h-type order products which are produced by the supplier (s). Constraint (3) ensures that at least one of the incoming trucks (i) loads the supply (s) of type G product and transports all products to the customer (c) at once. Constraint (4) ensures that if the incoming truck (i) moves towards the supplier (s), it selects three modes to exit the supplier. The first case is that the truck moves towards another supplier, the second one moves towards one of the cross-docks (cd), and the last one moves towards the customer (c). Constraint (5) ensures that if the incoming truck (i) moves from the source supplier (Sm) to the destination supplier (Sn), it selects one of three modes to exit the supplier (Sn). The first case is that the truck is moving towards another supplier, the second one is moving towards one of the cross-docks (cd), and the third one is moving towards the customer (c). Constraint (6) ensures that if the outgoing truck (j) moves towards the customer (c), it selects one of two modes to exit the customer (c). The first case is that the truck moves towards another customer and the second moves towards one of the cross-docks (cd). Constraint (7) ensures that if the incoming truck (i) moves from the source customer (cm) to the destination customer (cn), it selects one of two modes to exit the destination customer (cn). The first case is that the truck moves towards another customer and the second moves towards one of the cross-docks (cd). Constraint (8) is similar to constraint (7), and the difference between these two constraints is that in constraint (8), the outgoing truck (j) is considered in the constraint, and the third case, the outgoing truck crosses from a cross-dock to another cross-dock. Constraint (9) ensures that if the incoming truck (i) moves from the supplier (s) to customer (c), it selects one of two modes to exit the customer (c). The first case is that the truck is moving towards another customer, and the second case is that the truck is moving towards the cross-dock (cd). Constraint (10) ensures that the number of units of product that the incoming truck (i) transports from the supplier (s) to one of the cross-docks (cd) and unloads at the cross-dock is precisely equal to the number of units of products in the outgoing truck (j) loaded for the customer (c). Constraints (11) and (12) relate to the capacity of incoming and outgoing trucks and ensure that trucks do not load products beyond their capacity. Constraint (13) ensures that the total time of arrival of the vehicle to the customer, the time elapsed between the manufacturer and the customer, the time of unloading the cargo at the customer's place, and the waiting time of the vehicle should not exceed the specified time of departure for each customer. Constraint (14) guarantees that the total time of arrival of the vehicle to the customer, the time elapsed between the cross-dock and the customer, the time of unloading the cargo at the customer's place, and the waiting time of the vehicle should not exceed the specified time of departure of the vehicle from the customer's location. Constraint (15) ensures that a customer is assigned to a cross-dock if a truck connects the two. Constraint (16) ensures that inbound truck (i) from the supplier (i) only moves to a cross-dock. Constraints (17) and (18) are soft to calculate the number of early and late trucks to provide customer service in the norm time window.

3. Solution Methodology

In a small example, the designed mathematical model was first solved in GAMZ software by the ϵ-constraint method [37]. Then, with the development of the example, due to the large volume of model variables over time, it was not possible to solve with GAMZ software. Therefore, it was solved using NSGA-II MOPSO meta-heuristic algorithms.

3.1. Genetic Algorithm

Charles Darwin's theory, proposed in 1859, occupied a special place in optimization problems [38]. This theory is based on the best evolution, and it can be considered a starting point for evolutionary calculations. Genetic algorithms are random search algorithms whose idea is derived from nature. Genetic algorithms for classical optimization have successfully solved linear, convex, and similar problems, but genetic algorithms are much more efficient for solving discrete and nonlinear problems [39]. In nature, better generations emerge from a combination of better chromosomes. In the meantime, there are sometimes mutations in the chromosomes that may improve the next generation. Genetic algorithms also use this idea to solve problems [40]. Figure 2 show the schematic procedure of the NSGA-II algorithm, and then the details of the proposed genetic algorithm are described.

Step 1: Initialize a parent population P_k, where $k = 0$ with size N

Step 1.1: Create a representation for each chromosome from Uniform (0,1)
Step 1.2: Return restoration variables from generated chromosomes
Step 1.3: Check the feasibility related to restoration variables
Step 1.4: Call the mathematical model to obtain supply flow variables

Step 2: Generate an offspring population Q_k with size N from a parent population P_k

Step 2.1: Use a binary selection operator based on the sorting procedure
Step 2.2: Use a crossover operator (Alpha vector) with a crossover probability (Cp)
Step 2.3: Use a mutation operator (swap, slide, flip) with a mutation probability (Mp)
Step 2.4: Use an immigration operator with an immigration probability (Ip)
Step 2.5: Check the feasibility of the model

Step 3: Mate parent and offspring populations to create $R_k = P_k \cup Q_k$ with size $2N$

Step 4: Sort R_k to form non-dominated fronts

Step 4.1: Start with $h = 1$ (first front). For each chromosome i, identify the number of solutions that dominate i (ni), and create the set of solutions that i dominates (Si)
Step 4.2: Place each unplaced solution i with $ni = 0$ in the h^{th} front (F_h)
Step 4.3: For each solution i in F_h, find each chromosome j in Si and reduce nj by one
Step 4.4: If all solutions are placed in a front, stop. Otherwise, update $h \leftarrow h+1$ and go to Step 4.2

Step 5: Calculate a crowding distance

Step 5.1: For each objective m, sort all solutions in a particular front h (F_h) in a non-increasing order of the m^{th} objective function value
Step 5.2: Calculate the crowding distance of each chromosome i with respect to objective m (CD_{im})
Step 5.3: Compute the total crowding disatnce of each chromosome i

Step 6: Update a next parent population by selecting N best solutions from $2N$ solutions in R_k to form $P_{(k+1)}$ based on sorted fronts and crowding distance for the last front

Step 7: Update a new iteration ($k \leftarrow k+1$) and go to Step 2. When the stoping criteria is reached (k_{max}), stop the algorithm

Figure 2. A schematic procedure of the NSGA-II algorithm.

3.1.1. Chromosome Structure

Due to the complexity of the problem and the model, the chromosome consists of three components. These three components include the truck's movement between the origins and destinations and the loading modes of various products. First, how to produce the problem chromosome is described, and then for each example of the problem, in three levels: small, medium, and large, according to the number of trucks, manufacturers, cross-docks, customers, determination and capacity of trucks, time loading, unloading and handling at the cross-dock, distances between origins and destinations, and customer demand, the amount of production of producers are produced as a function of uniform distribution.

Table 3 shows the truck movement modes between the sources. Trucks identify products and loading locations before starting from the cross-dock. In Table 3, for example, four primary sources are considered: two suppliers and two cross-docks. According to Table 3, if the truck moves to the supplier or the cross-dock, it is assigned the number one; otherwise, it is given the number zero. The second column of Table 3, which contains the numbers (0, 0, 0, 1), states that the truck moves only towards supplier 1 and loads the products of supplier 1. Briefly in the table below, S1: supplier 1, S2: supplier 2, CD1: cross-dock 1, and CD2: cross-dock 2.

Table 3. Truck motion matrix at the origins.

Source	**S1**	**S2**	**CD1**	**CD2**	**S1S2**	**S1CD1**	**S1CD2**	**S2CD1**	**S2CD2**	**CD1CD2**	**S1S2CD1**	**S1S2CD2**	**S1S2CD1CD2**
CD1	1	1	0	1	1	0	1	0	1	0	1	1	1
S1	0	0	0	0	0	0	0	1	1	1	0	0	0
CD2	0	0	1	0	1	1	0	1	0	0	1	1	1
S2	0	0	0	0	0	1	1	0	0	1	1	1	1

Table 4 show the trucks' destinations after passing through the sources. For example, in this table, four main destinations are considered, including two customers and two cross-docks, and trucks can transport different modes of products to their destinations. According to Table 4, if the truck moves to the customer or the intersection dock, it is assigned the number one; otherwise, it is given the number zero. The second column of Table 4, which contains the numbers (0, 0, 0, 1), states that the truck moves only to customer one and unloads the customer's products. Briefly in Table 4, C1: customer 1 and: C2: customer 2 and CD1: cross-dock 1 and CD2: cross-dock 2.

Table 4. Truck movement matrix at destinations.

Destination	**C1**	**C2**	**CD1**	**CD2**	**C1C2**	**C1CD1**	**C1CD2**	**C2CD1**	**C2CD2**	**C1C2CD1**	**C1C2CD2**	**C1C2CD1CD2**
CD1	1	1	0	0	1	1	1	0	1	1	1	1
C1	0	0	0	0	0	0	0	1	1	0	0	0
CD2	0	0	1	0	1	1	0	1	0	1	1	1
C2	0	0	0	1	0	0	1	0	0	0	0	0

For example, four different types of products are used. These four types of products are delivered to customers by production suppliers and trucks. Table 5 show the different modes of loading products from suppliers in trucks. A truck can load other methods of products in its truck. According to Table 5, if the truck loads one of the product ordering modes, it will be number one; otherwise, it will be zero. The second column of Table 5, which contains the numbers (0, 0, 0, 1), states that the truck only loads product A.

Table 5. Matrix of product ordering modes.

Ordering Mode	A	B	C	D	AB	AC	AD	BC	BD	CD	ABC	ABD	ACD	BCD	ABCD
A	1	0	0	0	1	1	1	0	0	0	1	1	1	0	1
B	0	1	0	0	1	0	0	1	1	0	1	1	0	1	1
C	0	0	1	0	0	1	0	1	0	1	1	0	1	1	1
D	0	0	0	1	0	0	1	0	1	1	0	1	1	1	1

3.1.2. The Structure of the Cross Method

In the cross method, the production of new children is from the elite parents of the current generation. New children should inherit the main characteristics of parents and be more privileged than them. How children are produced depends on the structure of the chromosome. Using the tournament method as a selection mechanism, two chromosomes are selected as parents. The single-point cross is then performed separately for each part of the chromosome using row (horizontal) and columnar (vertical), randomly selected and described as follows. Table 6 show two samples of the parent chromosome to produce new offspring.

Table 6. Two hypothetical parent chromosomes.

First Parent												
1	1	0	1	1	0	1	0	1	0	1	1	1
0	0	0	0	0	0	0	1	1	1	0	0	0
0	0	1	0	1	1	0	1	0	0	1	1	1
0	0	0	0	0	1	1	0	0	1	1	1	1
Second Parent												
0	0	0	1	0	0	0	1	0	0	1	1	1
0	1	0	0	0	0	0	0	1	1	0	0	0
1	0	0	0	1	1	0	1	1	0	1	0	1
0	0	1	0	1	1	1	0	0	1	1	1	1

A—Array cross operator: In this case, we produce a random number in the range of the number of random devices. The generated random number indicates the array location of the cross in the parent chromosomes. Then, we replace the corresponding genes of the parents from the desired array, and new offspring are produced. For example, array 19 is selected at the cross of the array site 19 in the parent chromosomes, and then the corresponding genes of the parents are shifted from the array site 19 times in Table 7, and new offspring are produced.

B—Horizontal cross operator: In this case, we generate a random number in the range of the number of rows in the matrix at random. The generated random number indicates the location of the cross in the parent chromosomes. The selected line then replaces the corresponding genes of the parents, and new offspring are produced. For example, if the second row is selected, the junction of the second row is selected on the parent chromosomes, and then the corresponding parent genes are switched from the second row, as shown in Table 8, and new offspring are produced.

Table 7. Children of the cross-array operator.

The First Child												
0	0	0	1	0	0	0	1	1	0	1	1	1
0	1	0	0	0	0	1	1	1	1	0	0	0
1	0	0	0	1	1	1	0	0	0	1	1	1
0	0	1	0	0	1	1	0	0	1	1	1	1
The Second Child												
1	1	0	1	1	0	0	1	0	0	1	1	1
0	0	0	0	0	0	0	0	1	1	0	0	0
0	0	1	0	1	1	0	1	1	0	1	0	1
0	0	0	0	1	1	1	0	0	1	1	1	1

Table 8. Children of linear (horizontal) cross operator.

The First Child												
0	0	0	1	0	0	0	1	0	0	1	1	1
0	1	0	0	0	0	0	0	1	1	0	0	0
0	0	1	0	1	1	0	1	0	0	1	1	1
0	0	0	0	0	1	1	0	0	1	1	1	1
The Second Child												
1	1	0	1	1	0	1	0	1	0	1	1	1
0	0	0	0	0	0	0	1	1	1	0	0	0
1	0	0	0	1	1	0	1	1	0	1	0	1
0	0	1	0	1	1	1	0	0	1	1	1	1

C—Vertical cross operator: In this case, we generate a random number in the range of matrix columns. The generated random number indicates the location of the cross in the parent chromosomes. The selected column then replaces the corresponding genes of the parents, and new offspring are produced. For example, the fourth column is selected, the intersection is performed from the location of the fourth column in the parent chromosomes, and then the corresponding parent genes are switched from the location of the fourth column according to Table 9, and new offspring are produced.

Table 9. Children of the linear (vertical) cross operator.

The First Child												
1	1	0	1	1	0	1	0	1	0	1	1	1
0	0	0	0	0	0	0	1	1	1	0	0	0
0	0	1	0	1	1	0	1	0	0	1	1	1
0	0	0	0	0	1	1	0	0	1	1	1	1
The Second Child												
0	0	0	1	1	0	1	0	1	0	1	1	1
0	0	0	0	0	0	0	1	1	1	0	0	0
1	0	0	0	1	1	0	1	0	0	1	1	1
0	0	1	0	0	1	1	0	0	1	1	1	1

3.1.3. Structure of the Mutation Method

The mutation operator is mainly used to bring about transformation diversity and prevent divergence in the population. Due to the chromosome structure, the mutation operator, similar to the crossover operator, is performed as one of the array methods: row (horizontal) and columnar (vertical), which are randomly selected by the algorithm.

A—Array mutation operator: In this case, we produce a random number in the range of random arrays. The generated random number indicates the location of the mutation on the parent chromosome. Then, if the number in the array location is zero, it becomes one, and if it is one, it becomes zero. For example, array 19 is selected in parent one and the mutation is performed from array location 19 in the parent chromosomes. Then the corresponding parent gene from array location 19 is replaced by Table 10, and a new chromosome is produced.

Table 10. New chromosome derived from the array mutation operator.

1	1	0	1	1	0	1	0	1	0	1	1	1
0	0	0	0	0	0	0	1	1	1	0	0	0
0	0	1	0	0	1	0	1	0	0	1	1	1
0	0	0	0	0	1	1	0	0	1	1	1	1

B—Horizontal mutation operator: In this case, we generate a random number in the range of the number of rows in the matrix. The generated random number indicates the location of the mutation on the parent chromosome. The corresponding parent genes are then selected from the row location, which has values of zero and one, and we move the values of the two, and a new child is produced. For example, the second row is selected in the first parent and the mutation is performed from the second-row location in the parent chromosome. Then the corresponding parent genes are moved from the second-row location in Table 11, and a new chromosome is produced.

Table 11. New chromosome derived from the horizontal mutation operator.

1	1	0	1	1	0	1	0	1	0	1	1	1
1	1	1	1	1	1	1	0	0	0	1	1	1
0	0	1	0	1	1	0	1	0	0	1	1	1
0	0	0	0	0	1	1	0	0	1	1	1	1

C—Vertical mutation operator: In this case, we generate a random number in the range of the number of columns in the matrix. The generated random number indicates the location of the mutation on the parent chromosome. The corresponding parent genes are then selected from the column location, which has values of zero and one, and we move the values of the two, and a new child is produced. For example, the seventh column is selected in the first parent and the mutation is performed from the seventh-column location in the parent chromosome. Then the corresponding parent genes are moved from the seventh-column location in Table 12, and a new chromosome is produced.

Table 12. New chromosome derived from the vertical mutation operator.

1	1	0	1	1	0	0	0	1	0	1	1	1
0	0	0	0	0	0	1	1	1	1	0	0	0
0	0	1	0	1	1	1	1	0	0	1	1	1
0	0	0	0	0	1	0	0	0	1	1	1	1

3.2. Particle Swarm Optimization Algorithm—PSO

Kennedy and Eberhart (1995) presented the PSO algorithm in two papers for optimization problems whose continuous nature indicates the answers [41]. The population of answers is called a *swarm*. Each answer is like a *bird* in a group of birds and is called a *particle*. It is similar to the chromosome in the genetic algorithm. All particles have a *fitness value* calculated using the fitness function, and the particle fitness function must be optimized. The velocity vector of that particle determines the direction of motion of a particle. The PSO algorithm starts with random solutions (particles) and then seeks the optimal solution by synchronizing the particles in each iteration. If the decision variables, also their particles, are zero and one, each particle's velocity and position vectors in each iteration of the algorithm are calculated according to Equations (26)–(29).

$$V_{it} = w.V_{it-1} + c_1.r_1.(pBest_i - x_{it}) + c_2.r_2.(nBest_i - x_{it}) \quad (26)$$

$$-V_{max} \leq V_{it} \leq V_{max} \quad (27)$$

$$s_i = 1/1 + e^{V_{it}} \quad (28)$$

$$x_{it} = \begin{cases} 1 \; \rho \leq s_i \\ 0 \text{ otherwise} \end{cases} \quad (29)$$

According to the relation of 19, new velocity vectors of each particle based on the previous velocity of the particle itself (V_{it-1}), the best position the particle has ever reached ($pBest_i$) and the position of the best particle in the neighborhood of the particles obtained so far ($nBest_i$), are calculated. If the neighborhood of each particle contains all the particles in the group, then $nBest_i$ indicates the position of the best particle in the group, denoted by gBest. r_1 and r_2 are two random numbers with a uniform distribution between [0, 1] generated independently of each other. c_1 and c_2 are referred to as learning coefficients, they control the effect of pBest and nBest during the search process. w represents the weight coefficient of inertia. The value limits the particle velocity vector (V_{max}). V_{max} is a constraint that controls the global search capability of a particle group. Using the relation of 20 vectors, the velocity of each particle is converted to the change probability vector. In the above relation, s_i indicates the probability that x_{it} is equal to 1. Then, using the relation of 22 vectors, the position of each particle is updated. In the above relation, ρ is random with a uniform distribution between zero and one. The pseudo-code of group PSO is shown in Table 13.

Table 13. PSO pseudo-code.

```
For each particle
Initialize particle
End For
Do
For each particle
Calculate fitness value of the particle fp
/*updating particle's best fitness value so far)*/
If fp is better than pBest
set current value as the new pBest
End For
/*updating population's best fitness value so far)*/
Set gBest to the best fitness value of all particles
For each particle
Calculate particle velocity according to equation
Update particle position according to equation
End For While maximum iterations OR minimum error criteria is not attained
```

3.3. Validation of the Designed Model

Although many articles studied the issue of truck scheduling and transportation time minimization at the intersection dock, the issue of cost minimization (transportation, loading, unloading, and relocation) throughout the supply chain, considering the relationships and assumptions, was not previously studied. This article represents a new beginning for future work in this field. Therefore, since it is impossible to compare the results with other existing articles, a numerical example is presented in the next section, and the answers to the problem are compared using genetic algorithms and particle swarm.

Method of Generating Random Problems

Sample production problems are randomly generated in small, medium, and large groups. From each dimension of 7 sample problems, 21 sample problems are described according to Table 14 of the production. Then, the computational results will be presented, and finally, by repeating the algorithm implementations and using the uniform distribution function, the problem parameters are generated, and new numbers are generated in each sample. Additionally, the sensitivity analysis of the results is analyzed using the number of trucks, and in the end, the two algorithms are compared using different performance criteria. The solution of the model was obtained using MATLAB (R2019a) software. The problem was that the trucks would move from suppliers to customers or cross-dock and unload the loaded products after loading the products. To better understand how the two algorithms work, the problem-solving details of Example 6 are shown in a small size, which is almost the most straightforward example problem.

Table 14. Fixed parameters of the problems.

Parameters	**Problem 1**							**Problem 2**							**Problem 3**						
	1	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Number of incoming trucks	2	4	4	3	4	3	3	3	4	2	4	4	3	3	12	11	13	14	11	12	11
Number of outgoing trucks	2	4	3	4	4	3	2	2	3	3	2	3	2	2	11	12	11	12	11	10	12
Number of suppliers	4	3	4	4	5	3	2	10	9	9	8	7	8	11	18	17	17	19	18	16	20
Number of cross-dock	4	3	3	7	4	3	3	8	9	9	7	8	6	6	12	10	11	12	10	10	14
Product types	10	6	8	10	9	10	11	12	12	14	12	11	13	15	20	16	18	20	20	20	25
Number of customer	5	3	4	8	4	3	3	11	12	10	9	10	11	15	22	20	23	21	20	18	20

Several parameter values are generated using the uniform distribution function in this problem. Parameters that are generated randomly include the capacity of the trucks, the amount of customer demand, the amount of production of the manufacturers, the number of products, the fuel consumption rate, and the distance traveled by the trucks between the origins and the destinations. Sample parameter values are created and given in the relevant tables for each problem. Table 15 list the minimum and maximum values that the parameters can be assigned.

Table 15. Random parameters of the problem.

Customer demand	U(0,30)	U(0,30)	U(0,30)
Product supply rate	U(0,30)	U(0,30)	U(0,30)
Product weight	U(0,10)	U(0,10)	U(0,10)
Incoming truck capacity	U(0,10) × 1000	U(0,10) × 1000	U(0,10) × 1000
Outgoing trucks capacity	U(0,10) × 1000	U(0,10) × 1000	U(0,10) × 1000
Origin between destination distance	U(1,100)	U(1,100)	U(1,100)
Number of product type G	U(1,10)	U(1,10)	U(1,10)
Fuel consumption rate	U(1,20)	U(1,20)	U(1,20)

Two meta-heuristic algorithms for solving multi-objective problems, including the NSGA-II faulty sorting genetic algorithm and the MOPSO multi-objective particle swarm algorithm, were used to solve the proposed model. The Taguchi method was used to adjust the parameters of the algorithms. The advantage of the Taguchi method over other experimental design methods is that in addition to cost, obtaining optimal levels of parameters can be achieved in less time. One of the most important steps in this method is to select an orthogonal array that estimates the effects of factors on the mean response and variation. In this paper, the most suitable three-level test design is identified, and according to the Taguchi standard orthogonal arrays, the L9 array is selected as the appropriate test design to parameterize the proposed algorithms. A statistical measure of performance is considered the S/N $(signal\ to\ noise)$ ratio to adjust the optimal parameters, which includes the average and changes. This ratio is desirable. The considered response variable is the average of the four standard indices MID (mean ideal distance), MD (maximum spread or diversity), spacing, and NPS (number of pareto solution) for multi-objective meta-heuristic algorithms. Since this response variable is less, its corresponding S/N ratio is considered as Equation (30). The proposed meta-heuristic algorithms were implemented for each Taguchi experiment, and then the S/N ratios were calculated using Minitab 18 software. The optimal values of the parameters of each algorithm are shown in Table 16.

$$S/NRatio = -10\log\left(\frac{sum(y^2)}{n}\right) \tag{30}$$

Table 16. Optimal values of parameters in algorithms.

Algorithm	Parameters	Parameter Domin	Amounts
NSGA-II	Iteration	100–300	300
	Population size	50–100	100
	Intersection rate	0.6–0.8	0.8
	Mutation rate	0.1–0.2	0.2
MOPSO	Iteration	100–300	300
	Population size	50–100	100
	Cognitive constants, C1	1–3	3
	Social constant, C2	1–2	2

4. Results

Sample problem 6 was solved at the small size level with the fixed parameters listed in Table 4 and the random parameters listed in Table 6 with the four algorithms NSGA-II and MOPSO. Based on this, the sequence of truck transportation operations in sample case 6, for all four algorithms, is presented as the output analysis of the variables according to the following tables. Table 17 show the transport sequences of the first truck in sample problem 6 by solving the NSGA-II algorithm, and Table 18 show the transport sequences of the first truck in sample problem 6 using the MOPSO solution method.

Table 17. Truck transport sequence 1 with NSGA-II algorithm for sample problem 1.

Origin	Destination	Product Type	Number of Products	Shipping Sequence
Supplier 1	Cross-dock 1	E	7	1
Supplier 2	Cross-dock 1	F	15	
Supplier 3	Cross-dock 3	G	6	2
Supplier 3	Customer 1	D	14	3
Supplier 3	Customer 2	D	14	
Supplier 2	Customer 3	D	13	
Supplier 1	Customer 3	E	17	
Supplier 2	Customer 1	F	8	
Supplier 2	Customer 2	F	16	
Supplier 2	Customer 3	F	18	

Table 17. *Cont.*

Origin	Destination	Product Type	Number of Products	Shipping Sequence
Supplier 2	Customer 2	G	7	
Supplier 3	Supplier 1	E	7	
Supplier 2	Supplier 1	F	15	
Supplier 3	Supplier 1	F	16	4
Cross-dock 3	Cross-dock 1	D	14	5
Cross-dock 2	Cross-dock 1	F	16	
Customer 3	Customer 1	D	14	
Customer 3	Customer 2	E	8	
Customer 3	Customer 2	F	18	
Customer 3	Customer 2	G	13	6
Cross-dock 1	Customer 1	B	9	
Cross-dock 1	Customer 3	D	14	
Cross-dock 1	Customer 1	G	10	
Cross-dock 1	Customer 2	G	7	
Cross-dock 2	Customer 3	C	11	7
Cross-dock 3	Customer 1	E	17	

Table 18. Truck transport sequence 1 with MOPSO algorithm for sample problem 1 (small level).

Origin	Destination	Product Type	Number of Products	Shipping Sequence
Supplier 2	Cross-dock 2	D	8	
Supplier 2	Cross-dock 2	E	8	
Supplier 2	Cross-dock 2	H	11	1
Supplier 2	Customer 1	D	14	
Supplier 2	Customer 2	D	13	
Supplier 2	Customer 1	E	17	
Supplier 2	Customer 2	E	4	2
Supplier 2	Customer 3	E	8	
Supplier 1	Customer 3	D	14	
Supplier 2	Supplier 1	D	8	
Supplier 2	Supplier 1	H	11	3
Cross-dock 2	Cross-dock 1	D	12	4
Customer 3	Customer 2	E	8	
Customer 1	Customer 2	H	4	5
Cross-dock 2	Customer 3	C	17	
Cross-dock 2	Customer 1	E	17	
Cross-dock 2	Customer 2	E	4	
Cross-dock 2	Customer 3	G	7	
Cross-dock 1	Customer 3	E	17	6
Cross-dock 3	Customer 2	E	8	

4.1. Comparison of NSGA-II and MOPSO Algorithms

Tables 19 and 20 show the values related to the criteria of several answers, time to solve problems, distance from the ideal point, distance, and maximum coverage to compare NSGA-II and MOPSO algorithms.

Execution time—One of the crucial criteria for measuring the performance quality of an algorithm is its execution time, which in some articles is also referred to as execution speed. This criterion becomes essential when the dimensions and complexity of the problem increase. The execution time of these four methods in the three levels of small, medium, and large sample problems are given in Tables 19 and 20 and Figure 3. In general, the NSGA-II algorithm is more acceptable in terms of average runtime at both medium and large sample problem levels.

Table 19. Criteria values of the NSGA-II algorithm.

Example	Size	NSGA-II				
		NPS	Time (S)	MID	DM	Spacing
1	Small	100	878.22	1.0918	50964	0.8515
2	Small	97	526.19	1.0601	3351	0.9425
3	Small	100	898.23	1.0361	5745.4	0.9863
4	Small	100	1204.84	1.1609	5082.3	0.8294
5	Small	100	911.26	1.0537	5281.4	0.9158
6	Small	99	392.67	1.0077	3667.4	0.9317
7	Small	99	711.97	1.1094	4616	1.0001
	Mean	99.28	798.054	1.0742	4691.4	0.9226
1	Middle	100	2011.51	1.0466	9406.5	0.8803
2	Middle	100	2213.24	1.0494	9415	0.9962
3	Middle	100	3415.81	1.0453	11,761	1.0038
4	Middle	100	4313.86	1.043	11,291	1.0075
5	Middle	100	4201.49	1.0371	12,580	1.0718
6	Middle	100	3919.35	1.0394	13,449	0.9942
7	Middle	99	5077.08	1.0556	12,997	0.963
	Mean	99.85	3593.19	1.045	11,557.07	0.9881
1	Large	100	19,202.23	1.0627	19,654	1.1429
2	Large	99	21,020.54	1.0748	21,012	1.1436
3	Large	100	210,695.14	1.0452	20,654.12	1.1259
4	Large	100	230,458.87	1.0872	23,012.45	1.1248
5	Large	100	26,748.65	1.0925	24,896.87	1.0258
6	Large	99	25,874.96	1.0745	23,968.97	1.0387
7	Large	100	27,987.56	1.0998	25,984.23	1.0587
	Mean	99.714	22,715.28	1.0766	22,624.79	1.0941

Table 20. Criteria values of the MOPSO algorithm.

Example	Size	MOPSO				
		NPS	Time (S)	MID	DM	Spacing
1	Small	100	817.45	1.1166	2708.6	0.8495
2	Small	77	473.64	1.1234	1365.3	0.803
3	Small	99	831.9	1.0548	2972.3	0.9092
4	Small	94	1161.45	1.2043	2897.9	0.7604
5	Small	95	853.09	1.0943	3108.5	0.8189
6	Small	98	381.79	1.0829	2430	0.907
7	Small	95	650.25	1.1492	2324.6	0.7806
	Mean	94	738.51	1.1179	2453.88	0.8326
1	Middle	100	2044.69	1.0468	6090.3	0.9312
2	Middle	92	2320.03	1.0455	7155.5	1.0476
3	Middle	100	3451.65	1.0547	6141	0.8661
4	Middle	98	4364.47	1.049	7536.4	1.0063
5	Middle	98	4113.73	1.0404	7265.8	0.9996
6	Middle	100	3996.17	1.0364	8293.4	0.9286
7	Middle	96	5258.46	1.0625	6351.8	0.8655
	Mean	97.714	3649.88	1.0479	6976.3	0.9493
1	Large	100	19,795.71	1.0877	10395	0.8874
2	Large	100	22,101.36	1.0689	11,256	0.8658
3	Large	100	20,985.87	1.0589	10,365.85	0.8953
4	Large	100	21,895.3	1.0489	12,365.35	0.9587
5	Large	96	27,014.32	1.0845	12,985.36	0.8596
6	Large	100	26,579.89	1.0895	12,645.84	0.9741
7	Large	93	28,012.56	1.0114	13,586.96	0.8254
	Mean	98.42	23,769.27	1.06	11,942.91	0.8951

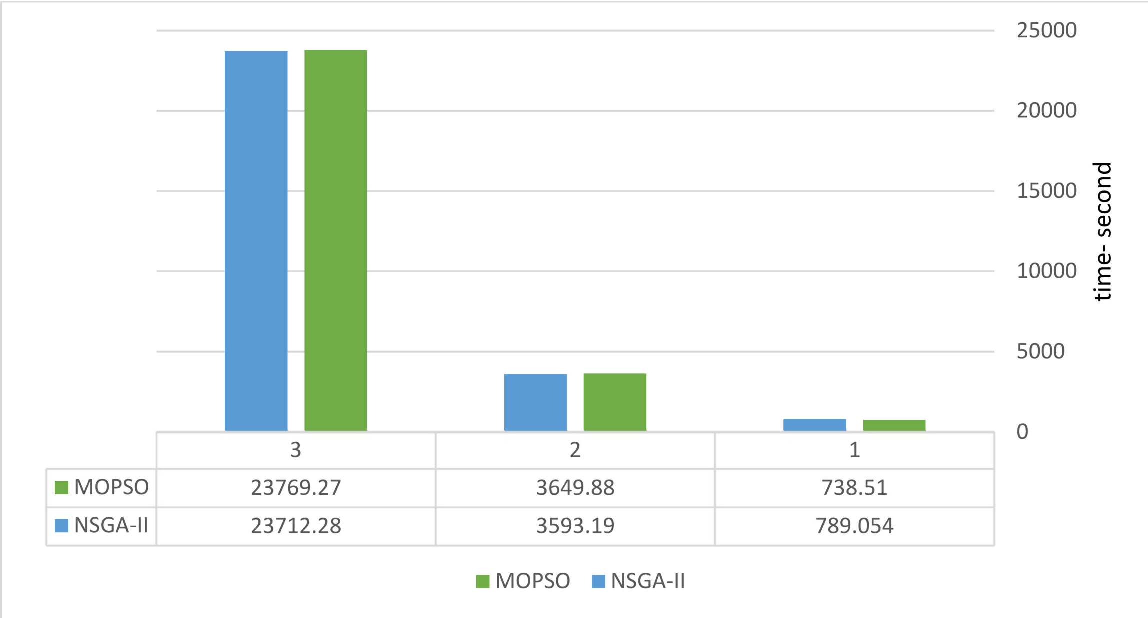


Figure 3. Comparison between the average execution time of NSGA-II and MOPSO.

4.1.1. Distance from the Ideal Point

The MID index is used to calculate the mean distance of Pareto solutions from the origin's so-called ideal point. Considering the MID, it is clear that the lower the value of this index, the higher the efficiency of this algorithm. The ideal point distance criterion, which measures the optimal close Pareto proximity measure, was calculated for 21 sample problems for the NSGA-II and MOPSO algorithms. In these 21 problems, the average values of the NSGA-II algorithm in small and medium problems were less than for the MOPSO algorithm. The DM index shows the variety of Pareto solutions. The higher the DM value is, the better the algorithm performs.

4.1.2. Spacing

The spacing criterion for each sample problem was calculated for the NSGA-II MOPSO algorithms, and the comparison of the mean of these two values for the sample problems was performed at three levels to determine the most desirable algorithm. The spacing criterion in the MOPSO algorithm was smaller than the NSGA-II algorithm and had better performance.

4.1.3. The Most Expansion

The maximum expansion criterion for the 21 sample problems was calculated for the NSGA-II and MOPSO algorithms. The criterion measures the maximum expansion density of Pareto archive solutions, and a simple method was used to calculate it, i.e., without considering the intermediate solutions, only the boundary solutions were used to plot the extent of Pareto archive solutions. In this criterion, the average of the calculations shows that the NSGA-II algorithm offers more comprehensive answers than the MOPSO algorithm.

5. Conclusions and Suggestions

The problem studied in this article was used to provide a model for the optimal sequence of trucks and the cost of operations within the supply chain concerning three objectives (minimizing the cost of transportation, minimizing the sequence of transporting trucks, and minimizing carbon dioxide emissions) [42–45]. The mathematical model approach is complicated due to the high number of variables and limitations related to the number of trucks sending and receiving and the number of products required to solve the problem. When increasing these variables, the dimensions of the problem and the solution time increase exponentially [46,47]. Therefore, two meta-heuristic algorithms NSGA-II and MOPSO, were used to solve the model. The results of the calculations were compared using four criteria. On average, the NSGA-II algorithm is more acceptable in runtime for 21 sample problems at the three small, medium, and large levels. In terms of distance from the ideal point, the NSGA-II algorithm is better. In the spacing criterion, which measures the density of Pareto archive solutions, the MOPSO algorithm scores better than the NSGA-II algorithm. The NSGA-II algorithm offers broader answers than the MOPSO algorithm at the maximum expansion criterion. Because research in this area is in its infancy, there is much opportunity for future research. Several areas in which research can be expanded are listed below.

Generalization of the proposed mathematical model for modelling in the presence of cross-dock systems with many entrances and exit doors.

It was assumed that temporary storage has unlimited capacity, while temporary storage is usually limited in practice. This real-world assumption can be added to the model.

Generalization of the proposed mathematical model by considering the multi-period mode.

Generalization of the proposed mathematical model of the problem by considering uncertain parameters (for example, considering fuzzy demand for customers) given the complex nature of docking systems.

Author Contributions: Conceptualization, I.M.-K. and N.S.; methodology, S.G. and N.S.; software, F.Y.; validation, I.M.-K.; formal analysis, S.G. and F.Y.; investigation, I.M.-K. and R.Č.; resources, S.G. and R.Č.; writing—original draft preparation, S.G. and N.S.; writing—review and editing, I.M.-K.; visualization, S.G. and R.Č.; supervision, I.M.-K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data of this study are available from the authors upon request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Rijal, A.; Bijvank, M.; de Koster, R. Integrated scheduling and assignment of trucks at unit-load cross-dock terminals with mixed service mode dock doors. *Eur. J. Oper. Res.* **2019**, *278*, 752–771. [CrossRef]
2. Serrano, C.; Delorme, X.; Dolgui, A. Scheduling of truck arrivals, truck departures and shop-floor operation in a cross-dock platform, based on trucks loading plans. *Int. J. Prod. Econ.* **2017**, *194*, 102–112. [CrossRef]
3. Seyedi, I.; Hamedi, M.; Tavakkoli-Moghadaam, R. Developing a mathematical model for a multi-door cross-dock scheduling problem with human factors: A modified imperialist competitive algorithm. *J. Ind. Eng. Manag. Stud.* **2021**, *8*, 180–201.
4. Motaghedi-Larijani, A.; Aminnayeri, M. Optimizing the admission time of outbound trucks entering a cross-dock with uniform arrival time by considering a queuing model. *Eng. Optim.* **2017**, *49*, 466–480. [CrossRef]
5. Gelareh, S.; Glover, F.; Guemri, O.; Hanafi, S.; Nduwayo, P.; Todosijević, R. A comparative study of formulations for a cross-dock door assignment problem. *Omega* **2020**, *91*, 102015. [CrossRef]
6. Xi, X.; Changchun, L.; Yuan, W.; Hay, L.L. Two-stage conflict robust optimization models for cross-dock truck scheduling problem under uncertainty. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *144*, 102123. [CrossRef]
7. Sahebi, I.G.; Mosayebi, A.; Masoomi, B.; Marandi, F. Modeling the enablers for blockchain technology adoption in renewable energy supply chain. *Technol. Soc.* **2022**, 101871. [CrossRef]
8. Nassief, W. Cross-dock Door Assignments: Models, Algorithms and Extensions. Ph.D. Thesis, Concordia University, Montréal, QC, Canada, 2017. Available online: https://spectrum.library.concordia.ca/id/eprint/982540/1/Nassief_PhD_S2017.pdf (accessed on 19 November 2021).
9. Nasiri, M.M.; Rahbari, A.; Werner, F.; Karimi, R. Incorporating supplier selection and order allocation into the vehicle routing and multi-cross-dock scheduling problem. *Int. J. Prod. Res.* **2018**, *56*, 6527–6552. [CrossRef]
10. Chargui, T.; Bekrar, A.; Reghioui, M.; Trentesaux, D. Simulation for Pi-hub cross-docking robustness. In *Service Orientation in Holonic and Multi-Agent Manufacturing*; Springer: Berlin, Germany, 2018; pp. 317–328.
11. Tirkolaee, E.B.; Goli, A.; Faridnia, A.; Soltani, M.; Weber, G.-W. Multi-objective optimization for the reliable pollution-routing problem with cross-dock selection using Pareto-based algorithms. *J. Clean. Prod.* **2020**, *276*, 122927. [CrossRef]

12. Wang, H.; Alidaee, B. The multi-floor cross-dock door assignment problem: Rising challenges for the new trend in logistics industry. *Transp. Res. Part E Logist. Transp. Rev.* **2019**, *132*, 30–47. [CrossRef]
13. Dondo, R.; Cerdá, J. The heterogeneous vehicle routing and truck scheduling problem in a multi-door cross-dock system. *Comput. Chem. Eng.* **2015**, *76*, 42–62. [CrossRef]
14. Zuluaga, J.P.S.; Thiell, M.; Perales, R.C. Reverse cross-docking. *Omega* **2017**, *66*, 48–57. [CrossRef]
15. Mohtashami, A.; Tavana, M.; Santos-Arteaga, F.J.; Fallahian-Najafabadi, A. A novel multi-objective meta-heuristic model for solving cross-docking scheduling problems. *Appl. Soft Comput.* **2015**, *31*, 30–47. [CrossRef]
16. Wisittipanich, W.; Hengmeechai, P. Truck scheduling in multi-door cross docking terminal by modified particle swarm optimization. *Comput. Ind. Eng.* **2017**, *113*, 793–802. [CrossRef]
17. Mohtashami, A. A novel dynamic genetic algorithm-based method for vehicle scheduling in cross docking systems with frequent unloading operation. *Comput. Ind. Eng.* **2015**, *90*, 221–240. [CrossRef]
18. Ponboon, S.; Qureshi, A.G.; Taniguchi, E. Evaluation of cost structure and impact of parameters in location-routing problem with time windows. *Transp. Res. Procedia* **2016**, *12*, 213–226. [CrossRef]
19. Gomes, C.F.S.; Ribeiro, P.C.C.; de Matos Freire, K.A. Bibliometric research in Warehouse Management System from 2006 to 2016. In Proceedings of the World Multi-Conference on Systemics, Cybernetics and Informatics, Orlando, FL, USA, 8 July 2018; Volume 22, pp. 200–204.
20. Birim, Ş. Vehicle routing problem with cross docking: A simulated annealing approach. *Procedia Social Behav. Sci.* **2016**, *235*, 149–158. [CrossRef]
21. Yin, P.-Y.; Chuang, Y.-L. Adaptive memory artificial bee colony algorithm for green vehicle routing with cross-docking. *Appl. Math. Model.* **2016**, *40*, 9302–9315. [CrossRef]
22. Mohtashami, A.; Fallahian-Najafabadi, A. Scheduling trucks transportation in supply chain regarding cross docking using meta-heuristic algorithms. *Ind. Manag. Stud.* **2014**, *11*, 55–84.
23. Sung, C.S.; Song, S.H. Integrated service network design for a cross-docking supply chain network. *J. Oper. Res. Soc.* **2003**, *54*, 1283–1295. [CrossRef]
24. Chen, P.; Guo, Y.; Lim, A.; Rodrigues, B. Multiple crossdocks with inventory and time windows. *Comput. Oper. Res.* **2006**, *33*, 43–63. [CrossRef]
25. Sung, C.S.; Yang, W. An exact algorithm for a cross-docking supply chain network design problem. *J. Oper. Res. Soc.* **2008**, *59*, 119–136. [CrossRef]
26. Wen, M.; Larsen, J.; Clausen, J.; Cordeau, J.-F.; Laporte, G. Vehicle routing with cross-docking. *J. Oper. Res. Soc.* **2009**, *60*, 1708–1718. [CrossRef]
27. Musa, R.; Arnaout, J.-P.; Jung, H. Ant colony optimization algorithm to solve for the transportation problem of cross-docking network. *Comput. Ind. Eng.* **2010**, *59*, 85–92. [CrossRef]
28. Dondo, R.; Méndez, C.A.; Cerdá, J. The multi-echelon vehicle routing problem with cross docking in supply chain management. *Comput. Chem. Eng.* **2011**, *35*, 3002–3024. [CrossRef]
29. Santos, F.A.; Mateus, G.R.; Da Cunha, A.S. The pickup and delivery problem with cross-docking. *Comput. Oper. Res.* **2013**, *40*, 1085–1093. [CrossRef]
30. Morais, V.W.C.; Mateus, G.R.; Noronha, T.F. Iterated local search heuristics for the vehicle routing problem with cross-docking. *Expert Syst. Appl.* **2014**, *41*, 7495–7506. [CrossRef]
31. Vincent, F.Y.; Jewpanya, P.; Redi, A.A.N.P. Open vehicle routing problem with cross-docking. *Comput. Ind. Eng.* **2016**, *94*, 6–17.
32. Wang, J.; Jagannathan, A.K.R.; Zuo, X.; Murray, C.C. Two-layer simulated annealing and tabu search heuristics for a vehicle routing problem with cross docks and split deliveries. *Comput. Ind. Eng.* **2017**, *112*, 84–98. [CrossRef]
33. Rahbari, A.; Nasiri, M.M.; Werner, F.; Musavi, M.; Jolai, F. The vehicle routing and scheduling problem with cross-docking for perishable products under uncertainty: Two robust bi-objective models. *Appl. Math. Model.* **2019**, *70*, 605–625. [CrossRef]
34. Baniamerian, A.; Bashiri, M.; Tavakkoli-Moghaddam, R. Modified variable neighborhood search and genetic algorithm for profitable heterogeneous vehicle routing problem with cross-docking. *Appl. Soft Comput.* **2019**, *75*, 441–460. [CrossRef]
35. Zhou, B.; Zong, S. Adaptive memory red deer algorithm for cross-dock truck scheduling with products time window. *Eng. Comput.* **2021**, *38*, 3254–3289. [CrossRef]
36. Liao, T.W. Integrated Outbound Vehicle Routing and Scheduling Problem at a Multi-Door Cross-Dock Terminal. *IEEE Trans. Intell. Transp. Syst.* **2020**, *22*, 5599–5612. [CrossRef]
37. Safari, H.; Ajali, M.; Ghasemiyan Sahebi, I. Determining the strategic position of an educational institution in the organizational life cycle with fuzzy approach (Case Study: Social Sciences Faculty of Khalij Fars University). *Mod. Res. Decis. Mak.* **2016**, *1*, 117–138.
38. Khalili-Damghani, K.; Tavana, M.; Santos-Arteaga, F.J.; Ghanbarzad-Dashti, M. A customized genetic algorithm for solving multi-period cross-dock truck scheduling problems. *Measurement* **2017**, *108*, 101–118. [CrossRef]
39. Corsten, H.; Becker, F.; Salewski, H. Integrating truck and workforce scheduling in a cross-dock: Analysis of different workforce coordination policies. *J. Bus. Econ.* **2020**, *90*, 207–237. [CrossRef]
40. Maknoon, Y.; Laporte, G. Vehicle routing with cross-dock selection. *Comput. Oper. Res.* **2017**, *77*, 254–266. [CrossRef]
41. Eberhart, R.; Kennedy, J. A new optimizer using particle swarm theory. In Proceedings of the MHS'95. Proceedings of the Sixth International Symposium on Micro Machine and Human Science, Nagoya, Japan, 4–6 October 1995; pp. 39–43.

42. Sahebi, I.; Masoomi, B.; Ghorbani, S.; Uslu, T. Scenario-based designing of closed-loop supply chain with uncertainty in returned products. *Decis. Sci. Lett.* **2019**, *8*, 505–518. [CrossRef]
43. Kusolpuchong, S.; Chusap, K.; Alhawari, O.; Suer, G. A Genetic Algorithm Approach for Multi Objective Cross Dock Scheduling in Supply Chains. *Procedia Manuf.* **2019**, *39*, 1139–1148. [CrossRef]
44. Arab, A.; Sahebi, I.G.; Modarresi, M.; Ajalli, M. A Grey DEMATEL approach for ranking the KSFs of environmental management system implementation (ISO 14001). *Calitatea* **2017**, *18*, 115.
45. Arab, A.; Sahebi, I.G.; Alavi, S.A. Assessing the key success factors of knowledge management adoption in supply chain. *Int. J. Acad. Res. Bus. Soc. Sci.* **2017**, *7*, 2222–6990. [CrossRef]
46. Sayed, S.I.; Contreras, I.; Diaz, J.A.; Luna, D.E. Integrated cross-dock door assignment and truck scheduling with handling times. *Top* **2020**, *28*, 705–727. [CrossRef]
47. Heidari, F.; Zegordi, S.H.; Tavakkoli-Moghaddam, R. Modeling truck scheduling problem at a cross-dock facility through a bi-objective bi-level optimization approach. *J. Intell. Manuf.* **2018**, *29*, 1155–1170. [CrossRef]

energies

MDPI

Article

Sustainable Rural Electrification Project Management: An Analysis of Three Case Studies

Laura Del-Río-Carazo *, Emiliano Acquila-Natale, Santiago Iglesias-Pradas and Ángel Hernández-García

Departamento de Ingeniería de Organización, Administración de Empresas y Estadística, ETSI de Telecomunicación, Universidad Politécnica de Madrid, Av. Complutense 30, 28040 Madrid, Spain; emiliano.acquila@upm.es (E.A.-N.); s.iglesias@upm.es (S.I.-P.); angel.hernandez@upm.es (Á.H.-G.)
* Correspondence: laura.delrio@upm.es

Abstract: Universal access to energy is a global challenge for sustainable development that requires granting last-mile access to energy services to rural and isolated communities. However, achieving access is not sufficient: it must be done affordably, reliably and with an adequate quality. Universal access to energy goes beyond the mere selection of a technical solution or infrastructure; it demands being able to design management models for projects aiming to guarantee that households may access energy services in a sustainable way. This study analyzes the main elements (i.e., governance, technological and business models) of management models in universal access to energy projects and their impact on the different dimensions of sustainability (i.e., social, environmental, and economic). The study then presents three case studies of rural electrification projects having different configurations of the management model, with special focus on the differences in the business model, and it analyzes their outcomes from a sustainability perspective. The analysis of the three case studies suggests that the choice of the business model is key to ensuring sustainability, with fee-for-service models giving the best results. The analysis also highlights the importance of collaboration and involvement of the communities in projects engaging multiple agents with different roles.

Keywords: management model; rural electrification; sustainability; governance; technology; business model

Citation: Del-Río-Carazo, L.; Acquila-Natale, E.; Iglesias-Pradas, S.; Hernández-García, Á. Sustainable Rural Electrification Project Management: An Analysis of Three Case Studies. *Energies* **2022**, *15*, 1203. https://doi.org/10.3390/en15031203

Academic Editors: Bernard Ziębicki and Edyta Bielińska-Dusza

Received: 30 December 2021
Accepted: 3 February 2022
Published: 7 February 2022

1. Introduction

Universal access to energy is essential to foster and guarantee the progress of less-favored and isolated rural communities [1]. Energy poverty has become a world problem and a threat to the environment, public health, safety, and the world economy [2]. According to the United Nations, the 17 Sustainable Development Goals (SDGs) cannot be achieved without sustainable energy, which is why high priority was given to affordable and non-polluting energy in SDG 7 [3].

The world population with access to energy has increased from 83 percent in 2010 to 90.2 percent in 2021. However, and despite the overall improvement in access to energy in the last years, rural areas in developing countries still show access levels that are far from the objectives declared in the 2030 Agenda [4]. In these cases, the main challenge still remains to address the "last mile" problem; that is, to reach to the most vulnerable and isolated communities: 759 million people do not have access to energy yet, of which most of them live in rural areas, representing a total of 85 percent of the global deficit in access to energy services [5].

The SDG 7 states that universal access to energy must be achieved by using renewable energies, improving the efficiency of energy systems, increasing international collaboration, extending the infrastructure and developing technologies [3]. Therefore, guaranteeing access to energy and energy services is not enough: it is imperative to provide reliable and affordable energy of sufficient quality [6]. Additionally, it is necessary to increase the production and delivery of energy services in a way that is compatible with the SDGs, a reason why the design of such provision must be made under the principles of universality, diversity and sustainability [3,7].

The origin of the "last mile" challenge is that it makes it very expensive, often prohibitive and not affordable, to provide remote rural communities with energy because the demand for energy from these communities is relatively low. Therefore, energy providers (ESCOs) discard those investments due to the impossibility to make them profitable without increasing their tariffs or having them subsidized by the state; instead, they focus on urban areas, densely populated and with higher average income population [8]. However, for universal access to energy to happen, it is necessary not only to provide access to energy, but also that the energy services are accessible: even when households may access a network or purchase individual energy generation systems, access rates may remain low due to the high initial costs, interconnection fees, wiring, and electric appliances. Hence, universal access to energy requires the development of business models that make access affordable, be it by means of subsidies or payment methods that are compatible with the economy of the households. Long-term sustainability of universal access to energy must also consider the local context and the different agents involved; for this reason, the underlying business models must be tailored to the characteristics of the population and be flexible enough to be consistent with local needs. Therefore, there is no single business model in universal access to energy, but rather different possibilities and characteristics that may be particular to each project. The big challenge is then being able to provide tailored solutions that do not slow down the projects aiming to achieve universal access to energy [5].

Because of the abovementioned barriers, project managers not only need to focus on using high-quality technology that may address local needs but must also ensure that the project's business model is consistent with cultural values, awareness, and the agents involved in the planning and execution of the project [9]. In other words, a correct management of the project will ensure its sustainability through the provision of a reliable, high-quality and affordable access to energy in rural areas [10].

To further clarify what constitutes a correct management in sustainable rural electrification projects, the main objective of this study is the elaboration of a comprehensive management model to analyze how different configurations of the model may affect sustainability. This is one of the main contributions of this study, as existing literature on rural electrification rarely adopts a managerial view of the projects. The analysis involves the examination of three different studies of real projects of rural electrification led by private entities. The remainder of the study is structured as follows. Section 2 lays out the possible configurations of the management model, with three different components (i.e., governance model, technological model, and business model), after observation of previous academic research on rural electrification projects. Furthermore, it links the impact of the different components of the management model with the three pillars of sustainability (social, environmental, and economic). Section 3 analyzes in further detail three study cases of rural electrification carried out by a private entity. Section 4 summarizes and discusses the main findings of the research. Finally, Section 5 presents the conclusions and limitations of the study.

2. Conceptual Framework

2.1. Management Modeling of Rural Electrification Projects

The configuration of a management model for rural electrification projects is complex and multifaceted. Real cases of rural electrification projects cover primarily the technological elements, project funding and the roles of the different agents involved [11], even though the terminology varies from one case to another [12]. From a wider perspective, the configuration of the management model requires the consideration of aspects relative to ownership, operation and maintenance, selection of technologies, viability and feasibility, funding, or stakeholders' roles, among others [11–14]. This study synthetizes these elements in three fundamental components: governance model, technological model, and business model (Figure 1). While governance may often be equated to the broader idea of project management, in rural electrification projects its scope extends to ownership of the initiative or project, the operation of energy provision and the relationships between actors/stakeholders [13,14]. A similar clarification is required in the case of the business model; while some may limit this component to the funding of the project, the business model covers more aspects, such as system acquisition, maintenance, or payment methods [12].

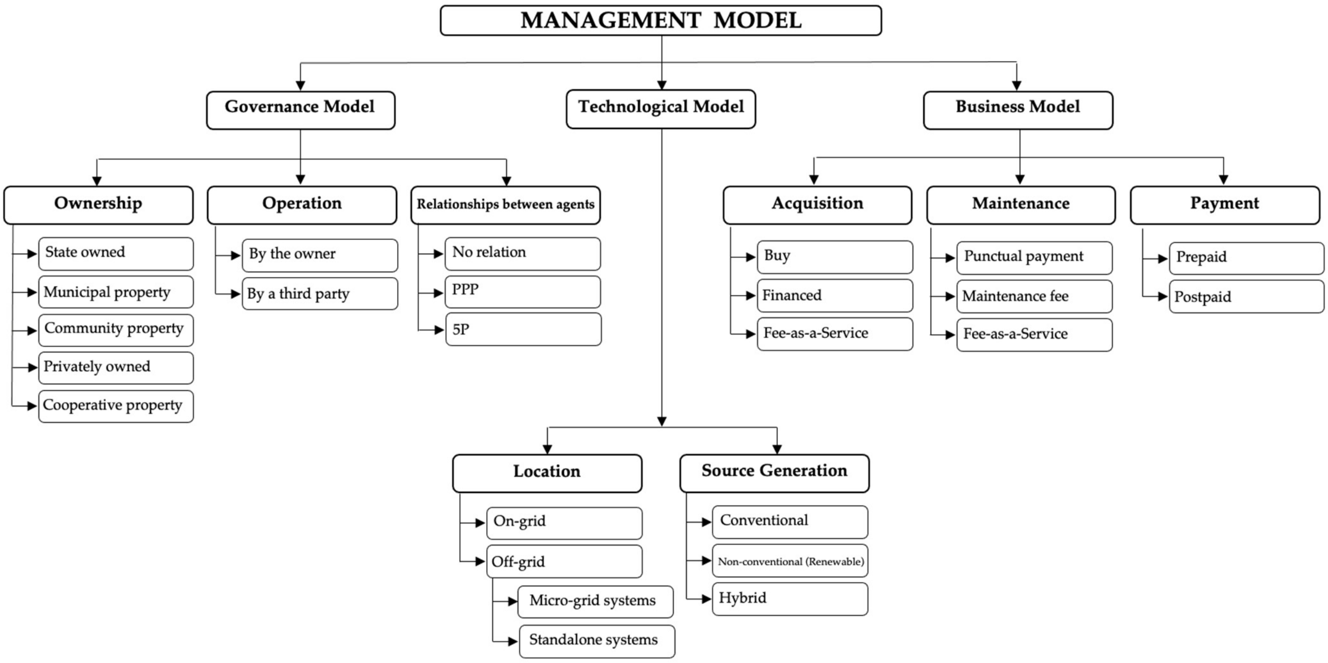


Figure 1. Management model for rural electrification projects.

2.1.1. Governance Model

Based on classifications of governance models of rural electrification projects found in prior research, we can highlight three main elements: ownership of the project, operation of the service and the relationships between agents [13,15,16]. Regarding ownership, the projects may be *state owned*, *privately owned*, *municipal property*, *community property*, and *cooperative property* [15]. *State ownership* refers to projects planned by the state and generally managed by existing electric companies [17]; in contrast, *privately owned* projects are those in which the systems and/or network that grant access to energy belong to the end users or a private company [18–20]. Ownership falls in *municipality* or local authority, or in the *community*, when the energy systems or network have been donated by an entity (public or private) but the control and management of the electric service has been transferred to the local authorities or to the community, respectively [21]. A final option is that of *cooperative* ownership of the project, in which a group of individuals oversees, implements and collectively owns the energy provision service to satisfy their energy access needs [22].

Regardless of ownership, the owner of the project is not necessarily responsible for the operation and maintenance of the service; from the perspective of operation and economic management of the service, there are two different options: either the service is operated *by the owner* or *by a third party* [13,23]. When projects are privately owned and operated by the owner, owners are responsible for the operation of the service, even though they may delegate preventive maintenance to end users and corrective maintenance to expert staff [24]; in *state-owned* projects, operation and preventive and corrective maintenance are generally subcontracted to electric companies; in the case of *municipal* or *community* ownership, citizens generally oversee operation and maintenance; finally, when service operation is overseen by a *third party*, the responsibility for operation and maintenance of the service is transferred to an entity that works autonomously from the owner; the staff of the third party has (or receives) the training and qualification to perform preventive and corrective maintenance, and the entity receives economic payments from periodic (weekly, monthly, yearly) service fees [25,26].

The third element of the governance model involves the relationships between the agents participating in the project. Because of the need to mobilize resources to broaden the coverage of the energy service, there are several actors involved in the energy service provision in rural electrification projects in remote areas [11]. From the review of prior experiences, three different forms of participation may be found: non-existent (the owner of the project executes it autonomously and independently), *public–private partnerships* (*PPPs*), and *pro-poor public–private partnerships* (*5P*) [27]. A PPP consists of agreements between the public and private sector, where resources from both are combined to provide the service; in a PPP, the public sector lays out the regulatory framework and protects the end users' rights, while the private participants contribute to the project with resources, knowledge and effective operation. The rise of initiatives oriented to improve universal access to basic services in developing countries has led to the emergence of a new type of relationship (5P), where not only states and private companies collaborate, but also incorporate other agents to the project, such as microfinancing institutions, banks or credit unions, universities and nonprofit, not-for-profit, and non-government organizations (NGOs) [17,21,27]. The main objective of 5P is the provision of services to poor communities, often ignored in PPP due to business risks. In 5P, poor people are not only users but also project partners; private companies may develop corporate social responsibility initiatives, public bodies may fulfill their obligation to provide universal access to basic services, and the communities may collaborate in broadening such access.

2.1.2. Technological Model

Rural electrification projects may rely on different technologies, depending on how dispersed are the potential users or their proximity to an existing electric network [28]. When the citizens and the communities live in areas that are close to an existing grid, and the orography is not a problem, *on-grid* systems (i.e., extending the existing network) comes up as an optimal solution [29]. On-grid systems provide enough electric power to connect several lighting devices, such as lamps, and other electric appliances [30]. In these cases, existing electric companies take on the initial infrastructure investment and operate the service, including the maintenance of the different systems [31]. When expanding the grid is not possible due to the fact of long distances between the users and the existing network, *off-grid* solutions are necessary; off-grid systems are independent systems, able to self-generate and store energy [32,33]. Among off-grid systems, there are different options depending on the dispersion of users. If the dispersion is low, *microgrids* generate energy at a local level and supply electricity to a reduced number of users, who are interconnected through a shared distributed system [19,34,35]; when the dispersion is high, *standalone systems* (e.g., *solar home-systems*) are the best solution, especially considering that the cost of grid connection increases with distance from grid [18,36–38].

Energy generation technologies vary depending on the chosen system. Based on the source of energy, they can be categorized as *conventional*, *non-conventional* (*renewable*), and *hybrid*. Conventional technologies use fossil fuel [38,39], whereas non-conventional technologies refer to those that use exclusively renewable energy sources [17,21,38,40,41] and hybrid technologies combine both [20,28,38,42]. As the availability of renewable sources of energy may be variable, non-conventional technologies make it necessary to use energy storage systems, such as batteries; hybrid systems generally try to avoid the use of batteries by incorporating diesel generators and reducing the capacity of storage systems [43].

2.1.3. Business Model

Ensuring that the business model of service provision is successful entails the collaboration of different agents (e.g., the state, donors, NGOs, or private companies) [44], and different alternatives can be offered to beneficiaries [45]. For instance, ownership of the energy generation system may fall on the end user (customer) or in the owner of the project (if state or privatelyowned). When customers own the system, they may have made a pay-up-front purchase or have their purchase financed in different payment installments using microcredits [46]. They are also responsible for the maintenance of the system, bearing the costs associated with maintenance and repairs; to avoid exceptional high expenses, another option is to make periodic payments (a maintenance fee), regardless of whether the systems needs repairing or not [45].

If the customer does not own the system, an *energy-as-a-service* (EaaS) model may be used. EaaS involves that the customer makes a periodic payment for energy provision that includes maintenance and substitution of the system when it reaches end-of-life or end-of-service-life [18,47]. EaaS improves the affordability of energy access because the energy provider maintains ownership of the system and has a duty to keep it operational [45]. Additionally, in EaaS there are two possible payment methods: *prepaid* and *postpaid* [48]; the former allows customers to pay only for the energy used, avoiding expenses when they do not have the money to make the payment (they would not have access to energy in the meanwhile), whereas the latter allows consumers to have access to energy even when they cannot make the payment occasionally (settling the debt in later installments) [49].

Finally, financing of all payments related to access to energy in rural electrification projects generally are subsidized either by the state or other public entities, or by private companies that bear a fraction of the cost of the equipment or the periodic fees; the subsidy may be equal for all customers or proportional to their income.

2.2. Rural Electrification Management Models and Sustainability

Achieving sustainability in rural electrification projects is one of the main challenges for developing countries [50,51]. The use of technologies that are tailored to rural areas widens access to energy [7], but selecting the right technology might not be enough, as it is necessary to consider all aspects related to sustainability throughout all the phases of the project, both at a technical and management level [52,53]. For example, choosing the right business model, achieving effective knowledge and technology transfer and including the beneficiaries in the decision making process facilitate the sustainability of the project [18,54,55].

Sustainable development refers to meeting "the needs and aspirations of the present generation without destroying the resources needed for future generations to meet their needs" [55]. A common view of sustainability is that of the three pillars, which differentiates between social, environmental, and economic sustainability [56]. Social sustainability refers to the ability of social identities, relationships, and values to continue in the future [57], which requires that social cohesion is sustained and that individual needs are met [58]. Environmental sustainability represents the ability to improve human well-being, while protecting the sources of raw materials and guaranteeing the integrity of ecosystems [59]. Economic sustainability refers to the ability of a project to sustain a given level of economic production indefinitely [60,61]. To better guide the decisions of rural electrification projects, the following subsections analyze the effect of the different possible configurations of the management model presented in Section 2.1 in each of the pillars of sustainability, by taking different frameworks defined to assess sustainability, either with a project management approach [62,63] or a rural electrification view [64–67].

2.2.1. Social Sustainability

The social dimension focuses on the improvement in the quality of life of the population, and it is associated with the fulfilment of their basic needs and their active participation in society. It is essential that the beneficiaries are involved in the development of the project, from its design to its implementation, so that the projects are adapted to the particular characteristics of the area and it is easier for the communities to appropriate the technology, thus ensuring their awareness and actual use of the solution [54,68].

From the management model, all three components (i.e., governance, technology, and business models) have a direct effect on different aspects related to social sustainability found in prior literature: funding, energy equity, availability of services, availability of support, profile of operation staff, degree of local participation, project duration, and default rate, or affordability.

Funding helps assess whether the beneficiaries can take care of the periodic expenses associated with access to energy, whether they should own the systems or whether the cost of the service is subsidized to facilitate affordable access to the least favored [68]. These decisions are affected by the governance model, through leadership and relationships between actors, and by the business model, when establishing the modality of acquisition.

Energy equity refers to the requirement that the project must focus on poorest communities and with higher barriers in access to energy, regardless of their social condition or the dispersion of such communities [63], which is highly related to the governance model, depending on the involvement of the community in decision making, and to the technology model, in system selection.

The service also must meet a minimum level of service offer and reliability, in what constitutes the availability of services. Such level varies depending on the characteristics of the community and must be analyzed as part of the project planning, considering the specific needs of each potential user. Availability of services may be assessed based on duration of energy shortages or blackouts as well as users' perceptions [64,69,70], and it is highly associated with the technological model. Additionally, beneficiaries may be provided with the necessary resources to repair the systems or replace them if they are beyond repair; in other words, they need to have available support, which must be both accessible and affordable to users [20,69]. Availability of support is therefore associated with the governance model, by defining who is responsible for service operation, and the business model, by the defined maintenance fees.

Regarding the profile of operating staff, the project must include personnel that has the required skills to operate and maintain the project, so that effective knowledge and technology transfer to the beneficiaries is possible [64]. Additionally, the project should include and empower women in such operation and maintenance tasks [68]. These aspects are affected by the governance model, depending on how community participation is incorporated into the project, which also affects the number of local population involved in the design and operation of the project [62,69].

Choices in ownership (i.e., governance model) and service modeling (i.e., business model) have an effect on the duration of the project. Rural electrification projects require an adoption and adaptation period among end users, as well as additional maturing time that facilitates analysis and fine tuning, which is why short and fast implementation projects with no subsequent monitoring should be avoided [68].

Finally, it must be possible to assess whether access to energy is really affordable for the beneficiaries or, on the contrary, it is necessary to revise the business model to change system acquisition or service provision to prevent abandonment by the users, measured as default rate [20,68,69].

2.2.2. Environmental Sustainability

Environmental sustainability considers the different aspects that impact natural resources and local ecosystems of the areas where the project will be implemented [6]. Decisions in the technology component of the management model are the ones with the most direct effect on environmental sustainability, which may be assessed through CO_2 emissions, impact on the ecosystem, replacement of other polluting sources or compatibility with future grid services.

CO_2 emissions facilitate quantitative comparison and selection of the most appropriate technology to achieve lower levels of pollution. It is necessary that the project management considers which is the right choice among the possible energy sources and systems [61]. Ecosystem impact is based on a qualitative and quantitative analysis of how respectful with the environment is the service infrastructure of the project, both at visual and acoustic levels. At the initiation phase of the project, the decision of the technology must consider and analyze the characteristics of the area and the population, as well as the dispersion of the community [62,64]. When developing rural electrification projects, current use of energy sources must be considered, so that the system to be introduced provides the highest reduction in the use of conventional sources and maximizes the use of non-polluting natural resources in the area [68]. Finally, the solution must guarantee the compatibility of the service with future developments and avoid the generation of technological waste due to obsolescence or abandonment of the system [68]; that is, the technology should be flexible and adaptable.

2.2.3. Economic Sustainability

The top priority of the project in the economic sustainability dimension of a rural electrification project should be to have the ability to autonomously bear the costs associated with the provision of the service in the future. Achieving economic sustainability requires that the costs of the electric service are high enough to maintain the systems operational in the long term but also low enough to guarantee affordability. Decisions of the business model directly affect economic sustainability and, in general, different business models are piloted, helping fine-tune the model until an optimal balance is achieved [5]. As seen in Section 2.1.3, decisions in the business model include system ownership and acquisition, maintenance mode, and payment methods. In developing countries, system acquisition is often prohibitive to the residents in rural areas. Therefore, ensuring economic sustainability involves the adoption of non-conventional business models where the end users only assume a percentage of the total cost.

Broadly, economic sustainability may be assessed by observing the profitability of the project, operation and maintenance costs, and capital and installation costs [68]. That is, the project must (1) be profitable enough to facilitate scaling up, which is why the business model must consider all the associated costs when fees and prices are set-up; (2) observe the economic resources necessary to ensure continuance of the project (higher economic resources entail higher fees and costs for beneficiaries); (3) consider the initial investment to deploy the technical system for energy provision (higher investment in more difficult implementations).

Table 1 shows a summary of the potential impact of decisions in the configuration of the business model on the three pillars of sustainability. The following section analyzes the effect of different decisions in the configuration of the management model in the sustainability of three real projects of rural electrification.

Table 1. Impact of decisions in the management model on sustainability in rural electrification projects.

Dimension		Model Component		
		Governance Model	Technological Model	Business Model
Environmental	CO_2 emissions		X	
	Impact on the ecosystem		X	
	Replacement of other polluting sources		X	
	Compatibility with future grid service		X	
Social	Funding	X		X
	Subsidies	X		X
	Energy equity	X	X	X
	Availability		X	
	Maintenance availability	X		X
	Profile of operators	X		
	Project duration	X		X
	Degree of local ownership	X		
	Default rate			X
Economic	Profitability			X
	Operating and maintenance costs	X		X
	Capital and installation costs		X	

3. Case Studies

3.1. Overview and Previous Considerations

This section showcases the analysis of three rural electrification projects in remote areas of Peru and Mexico. The three projects were led and developed by acciona.org, the corporate foundation of ACCIONA. Acciona.org's projects are based on four fundamental principles: (1) the projects are aligned with the main activity of the corporation with impact on human development (energy, water, and sanitation), which helps take advantage of the knowledge, expertise, and developed networks on these areas in developing regions while also empowering local employees; (2) prioritization of projects in areas that are less attended by other institutions, primarily impoverished rural and remote areas, where service provision is not planned; (3) the main objective of the projects must be the design of solutions that are sustainable in the long term. To do so, affiliate non-for-profit organizations are established; the affiliate organizations act as service providers, which facilitate the creation of long-term relationships with the beneficiaries; (4) collaboration with other local, national, and international organizations, including public, private and academic institutions, as well as other civil society organizations and local communities.

The three projects share some characteristics in their configuration of the management model. The governance model is based on private ownership of the projects, initiated by acciona.org and executed by their national affiliates, in this case acciona.org Perú and acciona.org México. The relationship model is 5P, with different collaborating actors at all levels. An advantage of the 5P configuration is that it guarantees the support of larger public and private entities to promote the project while bringing closer the potential beneficiaries by means of existing communication channels that facilitate adaptation of the project (e.g., local population, banks and credit unions, NGOs) as well as innovation through collaboration with academic and research institutions. 5P models also help overcome a big limitation of purely private ownership with no relations, where the design and the decisions in the other elements of the management model are mostly driven by the risk and low profitability of this kind of projects, which hinders the involvement of the local communities, the understanding of their needs and adaptation of the projects [48,71].

Except for slight differences, the three case studies include similar configurations of their management models in the governance (privately owned, 5P) and technology components (non-conventional, off-grid standalone systems; the technology of the three projects is based on solar home systems due to the dispersion of the communities and long distances to the electric network). Thus, even though the main implications of this configuration on the sustainability of the project will be analyzed, the main focus of the analysis will be the impact of the decisions related to the configuration of the business model on the sustainability of the projects. The following subsections introduce the setting of the three projects and analyze their management model according to the components presented in Section 2.

3.2. Case Study 1: Luz en Casa Cajamarca

Peru had a poverty rate of 30.1 percent in 2020. Access to electricity now extends to 98.35 percent of the country, but this figure drops to 92.45 percent in rural areas [71]. The department of Cajamarca, with 1.5 million inhabitants, has the lowest electrification rate in the country due to the wide dispersion of households in rural communities, which account for 70 percent of the population [72]. The "Luz en Casa Cajamarca" project (Table 2) was developed by the Spanish acciona.org foundation and the Peruvian civil association acciona.org Peru—the affiliate of the acciona.org foundation in Peru. The main objective of the project was to improve access to energy in the region of Cajamarca.

Table 2. "Luz en Casa Cajamarca": Project overview.

Project Title	*Luz en Casa Cajamarca*
Beneficiaries	Residents in Cajamarca, Peru
Project Period	2009–2021
Institutions	acciona.org foundation acciona.org Peru Banco Interamericano para el Desarrollo (BID)

3.2.1. Governance Model

"Luz en Casa Cajamarca" is a privately owned project led by acciona.org. In this project, members of the community are selected to work for acciona.org as freelance technical staff, and they oversee installation, set-up, and corrective maintenance of the systems, and provide support in shortage and reconnection tasks.

Local management of the project is performed by acciona.org, which assumes the project's operational tasks. Acciona.org is supported by a network of volunteers who provide occasional collaboration and by the Committees of Photovoltaic Electrification (CEFs). CEFs are a key agent in the operation of the project, acting as intermediaries between acciona.org and end users, helping in system inspection tasks and preventive maintenance, and collecting, transporting, and depositing the periodic fees associated with the service.

The relationship model can be labeled as 5P, including the collaboration of the acciona.org Foundation as promoter, funding body, coordinator, and supervisor; acciona.org as promoter and long-term operating agent; Ministerio de Energía y Minas (MEM) and Organismo Supervisor de la Inversión en Energía y Minería (OSINERGMIN) as regulators; Banco Interamericano para el Desarrollo (BID) as co-financer; Universidad Politécnica de Madrid (UPM) as academic and technical advisor; municipalities as partners and communities; CEFs as users and representatives.

3.2.2. Technological Model

Electricity was generated by second-generation solar home systems (SHS), standalone portable equipment that use renewable energies and allow to reach homes that fall out of the grid extension plans. SHS are solar photovoltaic generators rated between 11 and 100 Wp (Watt-peak) and have a storage battery [73]. Second-generation SHS are equipment specifically designed to optimize solar energy use, with higher capacity and efficiency than first-generation systems but lower required power. A novelty of these systems is that they feature a DC-DC voltage adapter for radio to allow radio connection of different voltages below DC 12 V and a socket to charge mobile phones [74]. Therefore, the service provided by the SHS in the project allows up to four hours of light using spotlights and the charge and use of entertainment and communication equipment, such as mobile devices.

3.2.3. Business Model

The business model was based on EaaS, where a monthly fee is charged for service provision. In this model, the users did not buy the systems: the systems were owned by acciona.org, which also oversaw maintenance and replacement in case of system failure or end-of-service-life. The decision to implement EaaS was made upon a cost analysis that showed that it was the only option that could support sustainable operation and maintenance costs, even assuming that the complete initial investment would not be recovered. To ensure affordable tariffs, it was necessary to negotiate with the Peruvian government to design a policy and regulatory framework for regulated tariffs in rural electrification with off-grid photovoltaic systems, and to incorporate the tariff into the national cross-subsidy system. The system established that 80 percent of the fee was paid by the state, and end users payed the remaining 20 percent of the fee. These amounts were set after consideration of the average household expenditure of 16.4 soles in access to energy (kerosene, candles, batteries) prior to the start of the project and the calculation of operation costs of the project to ensure sustainability. Prior to the coming into effect of the framework, the service fee was 15 soles per month, whereas after the implementation of the project, the fee was reduced to 10 soles per month, which was paid periodically once the service was provided (i.e., a postpaid system). Figure 2 shows a summary of the management model of the "Luz en Casa Cajamarca" project.

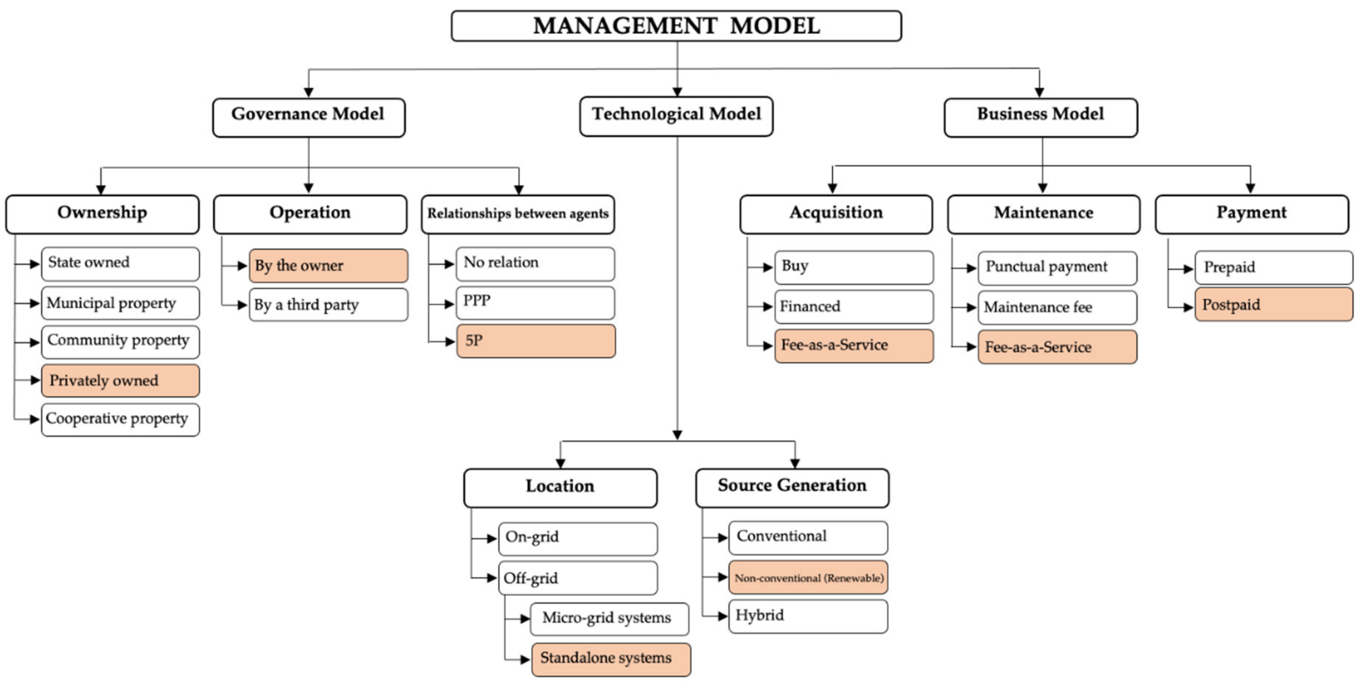


Figure 2. Configuration of the management model of the "Luz en Casa Cajamarca" project.

3.2.4. Main Results and Impact on Sustainability

"Luz en Casa Cajamarca" provides energy to 3910 households spread through 188 different communities after 12 years. With the project, acciona.org set in motion a social model that is close to the community and the users, who are not only beneficiaries of the service but can also take part in the operation and management of the project. The data from quantitative questionnaire-based satisfaction surveys of all users showed high rates of acceptance of the project among beneficiaries; additionally, the model ensured affordable access to energy, as default rates dropped from 3.03% to 0.19%. Awareness and sensitivity activities in the communities have increased credibility and seem to validate the management model. Users highlight time availability as one of the main advantages of the system, as they now have study and cooking time at night.

The project contributed to prevent the emission of 1544 tons of CO_2 per year and the generation of 1.65 tons of battery waste, with a minimal environmental impact due to the use of SHS that do not require the deployment of any additional infrastructure. Energy savings for households was estimated to be 656,880 soles per year (approximately EUR 163,000 per year).

The project made energy fees affordable for users with a balance between revenue and costs that ensures the economic viability and continuity of the project. The technology also helped reduce initial costs associated with infrastructure deployment: standalone SHS cost 2000 soles, compared to a cost of 70,000 soles for grid extension in these areas.

From a sustainability perspective, we observed two main shortcomings of the project. The first of them was related to corrective maintenance and operation, both at economic and human levels; because of the isolated and remote location of households, it is very difficult to supply repair parts, as well as to effectively repair faulty systems and collect service fees. The second shortcoming had to do with the low availability of qualified technical staff; even though the project put emphasis on the identification of users with communication and social mobilization skills to increase awareness and reach all potential beneficiaries, it is still necessary to identify residents with the minimum required technical skills.

3.3. Case Study 2: Luz en Casa Oaxaca

In 2010, 3 million people (2.6 percent of the population) did not have access to energy in Mexico yet. In Oaxaca, this percentage rose to 5.3 percent due to the remote and isolated location of the households [75]. The "Luz en Casa Oaxaca" program (Table 3) was ideated by the acciona.org foundation and the local acciona.org México, analogously to "Luz en Casa Cajamarca". The main objective of the project was to improve access to energy in the state of Oaxaca. The project is now included in the broader EncASa Oaxaca program, which seeks to provide integral and universal access to different basic services: electricity, drinking water, sanitation, and clean cooking.

Table 3. "Luz en Casa Oaxaca": Project overview.

Project Title	*Luz en Casa Oaxaca*
Beneficiaries	Residents in Oaxaca, México
Project Period	2012–2021
Institutions	acciona.org foundation acciona.org Mexico Gobierno del Estado de Oaxaca Agencia Española de Cooperación Internacional para el Desarrollo (AECID) Agencia Mexicana de Cooperación International para el Desarrollo (AMEXCID)

3.3.1. Governance Model

Same as "Luz en Casa Cajamarca", this project was privately owned by the acciona.org Foundation and acciona.org Mexico. Acciona.org Mexico is formed by a team of local technical staff from the country, which facilitates the communication with the communities (indigenous habitants represent 35 percent of the population in Oaxaca and the region is the most linguistic diverse in the country, with more than seven languages and dialects spoken, such as Mixteco, Zapoteco, and Chinanteco). Acciona.org México is in charge of local management and operation of the project.

The relationship model was 5P, with the collaboration of the acciona.org foundation as promoter, funding body, coordinator and supervisor; acciona.org México as promoter and responsible of the project in the long term; Gobierno del Estado de Oaxaca, Agencia Española de Cooperación Internacional para el Desarrollo (AECID), and Agencia Mexicana de Cooperación International para el Desarrollo (AMEXCID) as co-financers and intermediaries. The international organization KIVA participated as micro-financers, local municipalities acted as partners, and the communities and CEFs participated as end users and representatives.

3.3.2. Technological Model

The project consisted of the deployment of third-generation SHS, or pico photovoltaic systems. An additional benefit of third-generation systems when compared to second-generation SHS (such as those used in "Luz en Casa Cajamarca") is that they are more compact, lighter, easier to install and use (plug and play), and that they have integrated LED lights that allow for more efficient use of energy, in turn extending the duration of the batteries [74]. Third-generation SHS also use lithium batteries (instead of lead batteries), further reducing the weight of the system which, in turn, facilitates transportation to the communities [76].

3.3.3. Business Model

In "Luz en Casa Oaxaca", the end users acquired and owned the systems due to the impossibility of implementing EaaS models when the project started due to regulatory constraints. In this user-ownership model, end users paid for half of the cost of the system and the other half was subsidized by the project's funding bodies. Additionally, if a user could not afford the payment up front, different installments could be made by participating in a micro-credit program directed by KIVA (this program was only active in 2014). As end users owned the systems, they were responsible for maintenance, which entails additional costs beyond the warranty period of the systems.

The model requires higher availability of maintenance than EaaS because the end users have to be able to reach acciona.org's technical staff for diagnostic and repairing tasks. This decision also has an impact on the governance model, by delegating operational tasks in each area to local entrepreneurs who, from the so-called Centros Luz en Casa (CLCs), provide support and receive fee payments; they also establish franchises to sell appliances that are compatible with the SHS in order to extend the functionalities of the systems beyond lighting. CLCs are usually already existing local businesses located in reference sites that dedicate part of their space and time to support "Luz en Casa Oaxaca" users. Local entrepreneurs receive training to provide effective corrective maintenance and keep constant communication with the project's management bodies for fee and stock management; in return, they receive a commission fee for each repaired system or sold item. Currently, the project has five CLCs and four Centros EncASa (the latter offer support for sanitation, cooking and drinking water services, in addition to SHS systems and compatible appliances).

Figure 3 summarizes the management model of the "Luz en Casa Oaxaca" project.

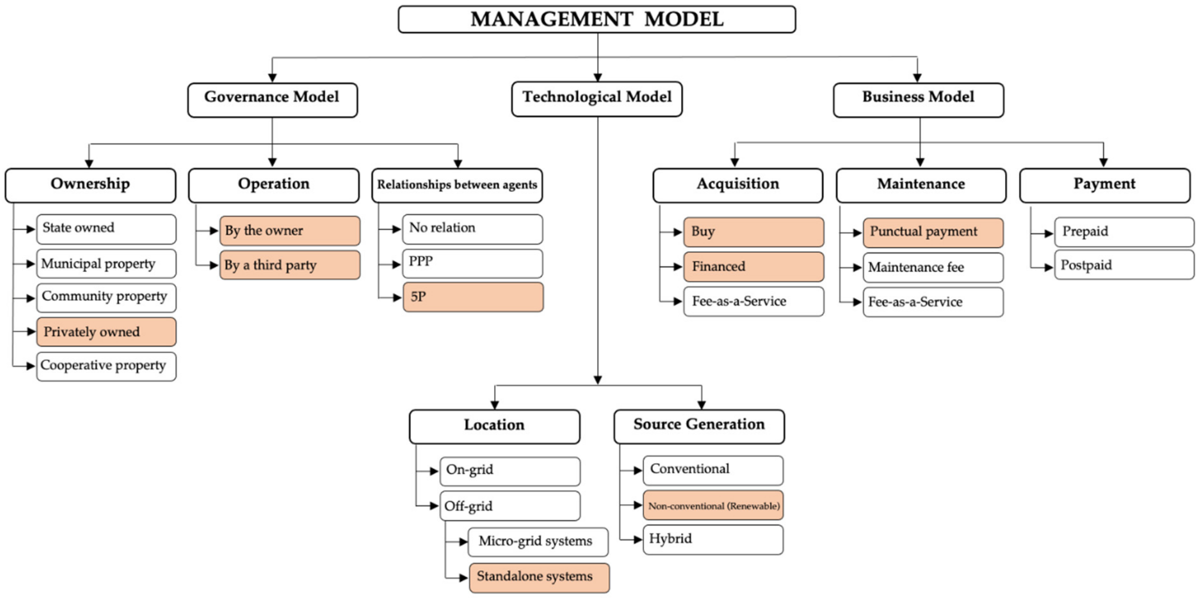


Figure 3. Configuration of the management model of the “Luz en Casa Oaxaca” project.

3.3.4. Main Results and Impact on Sustainability

The project, including Luz en Casa Oaxaca and EncASa Oaxaca, provided energy access to 8525 households in 628 communities after 9 years. Acciona.org subsidized the systems through a partnership involving several public and private entities, ensuring affordability for the most needed and improving universal access. The multi-agent configuration, supported by the CEFs and CLCs, provided higher availability of repairing staff than the “Luz en Casa Cajamarca” project through the identification and training of personnel with technical skills, in addition to awareness and social sensibilization skills. Three out of the nine local entrepreneurs were women who have become referents in the communities they provide support to, advancing towards gender equality. The partnership with public agents helped not only subsidize the systems but also improve and facilitate communication with the communities and a previous identification of the communities that would benefit from the project.

The SHS helped prevent the emission of 1075 tons of CO_2 per year and 12.42 tons of uncontrolled battery waste, with low impact on the environment. Household energy savings were estimated at 18.75 M pesos per year (approximately EUR 758,200 per year).

The subsidization program reduced cost acquisition in half, facilitating affordability, and the SHS reduced initial and deployment costs.

We observed two elements that could be improved from a sustainability perspective. First, maintenance costs may be high for end users. Because of the business model, costs associated with maintenance and repairing are not included in the price and, therefore, must be bore by the users, increasing costs in the case of system failure. Consequently, repair rates were low and, in some cases, the systems were abandoned when they stopped working because users could not afford the cost associated with repairing or replacing the system. Second, subsidization of system acquisition makes it necessary to increase awareness and sensibilization, as having the system subsidized increases the perception of higher costs if replacements are needed, which in turn may increase system abandonment rates. However, the alternative is to use conventional sources of energy, which are more harmful for both end users and the environment.

3.4. Case Study 3: Luz en Casa Amazonía (Napo)

In the Amazon rainforest area, only 82.7 percent of the population has access to electric energy [71], which means that about one in five people do not have access to energy. The “Luz en Casa Amazonía” Project (Table 4), designed by the acciona.org foundation and acciona.org Perú, aimed to improve access to electric energy of indigenous communities in the Peruvian Amazon rainforest.

Table 4. "Luz en Casa Amazonía": Project overview.

Project Title	*Luz en Casa Amazonía*
Beneficiaries	Residents in the Peruvian Napo, Ucayali and Amazonas River basins
Project Period	2016–2021
Institutions	acciona.org Foundation acciona.org Peru Agencia Española de Cooperación Internacional para el Desarrollo (AECID) Fondo Nacional de Desarrollo Científico, Tecnológico y de Innovación Tecnológica (FONDECYT)

3.4.1. Governance Model

Analogously to the previous two projects, "Luz en Casa Amazonía" was privately owned by the acciona.org foundation and acciona.org Peru. Acciona.org Peru is supported by CEFs and has CLCs for local management and operational tasks, including fee collection and payment, repairs, and sales.

The relationships are 5P, with the collaboration of the acciona.org foundation as promoter, funding body, coordinator, and supervisor; acciona.org Peru as promoter and long-term operator; Ministerio de Energía y Minas (MEM) and Organismo Superior de la Inversión en Energía Minera (OSINERGMIN) as regulators and policymakers; the Peruvian Government, Agencia Española de Cooperación Internacional para el Desarrollo (AECID), and Fondo Nacional de Desarrollo Científico, Tecnológico y de Innovación Tecnológica (FONDECYT) as co-financers; Universidad Politécnica de Madrid (UPM), Fundación de Ingenieros del ICAI para el Desarrollo (FICAID), and the Instituto de Investigación Tecnológica (IIT) as academic and technical advisors and partners; municipalities as partners; communities, CLCs (four), and CEFs as users, representatives, and micro-franchises.

3.4.2. Technological Model

The technology applied for service provision was based on third-generation SHS (same as in "Luz en Casa Oaxaca"), but using the pay-as-you-go (PAYG) functionality of the system to simplify the payment process. According to the World Bank, PAYG is one of the most effective solutions to provide decentralized access to energy in remote communities of developing countries [77]. PAYG systems, which were not used in the previous two projects, allow for a prepaid system of energy provision in which the end user pays a fee for a code that unblocks the SHS for a period of time. Once that period expires, the user must complete another payment and a new unblocking code is generated, or else the SHS will be blocked. Therefore, PAYG systems facilitate remote management of off-grid systems, reducing default rates and the risk associated with the initial investment [78].

3.4.3. Business Model

As in the "Luz en Casa Cajamarca", the energy was provided as EaaS. The business model improves the affordability of the technology: users can also benefit from cross subsidies and the tariff is regulated; therefore, end users only pay 20 percent of the total costs (approximately 9 soles per month). The main difference with the "Luz en Casa Cajamarca" project was that PAYG systems give more freedom to end users, which can accommodate their consumption to their disposable income.

Figure 4 summarizes the management model of the "Luz en Casa Amazonía" project.

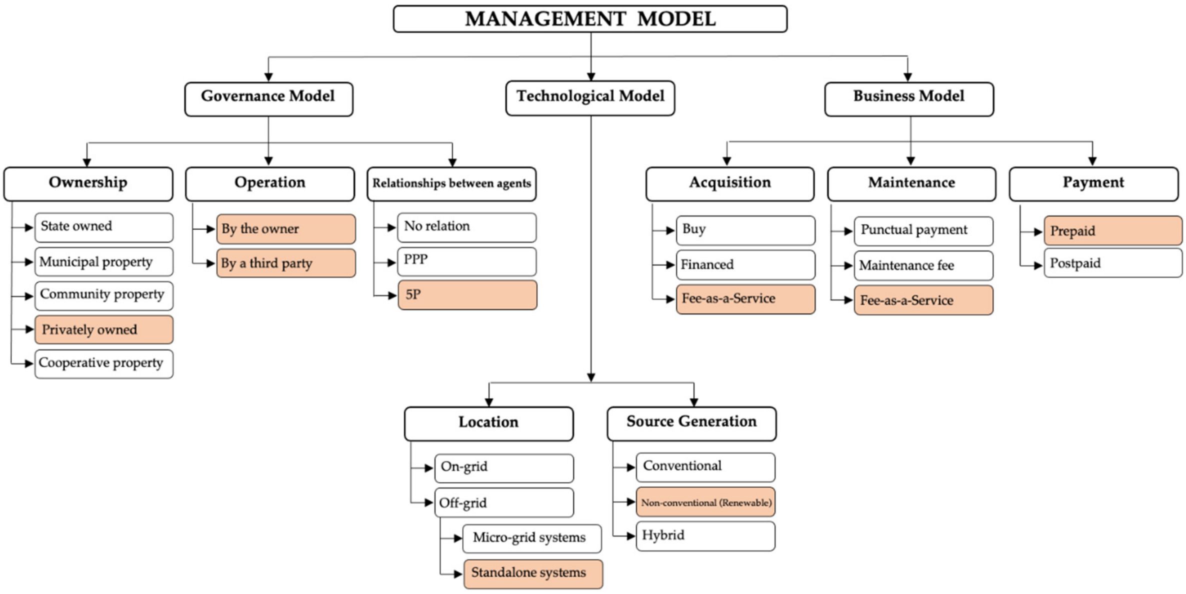


Figure 4. Configuration of the management model of the "Luz en Casa Amazonía" project.

3.4.4. Main Results and Impact on Sustainability

The project provided access to energy to 1518 households in 58 communities after 5 years. From a social sustainability perspective, acciona.org spread out a clean electrification solution for remote rural indigenous communities that minimizes the use of fossil fuel. According to satisfaction surveys collected by the project promoter with replies to a quantitative questionnaire of all participants in the pilot project, all the beneficiaries (100 percent) reported the highest level of satisfaction with the use of the SHS, and the majority of them (98 percent) were also satisfied with their energy savings. The multi-agent model and the incorporation of the CEFs and CLCs make service management and operation viable, as the households are only accessible by the river, and the weather conditions (temperature and rain) are extreme, which further complicates distribution and support.

The implementation of PAYG systems also has a positive impact in operation and management because prepaid installments help reduce default rates (which are close to zero) and delays in fee payments (a reduction of 83 percent, from 68 to 11 days). CLCs have made 80 percent of system repairs (including a 13.2 percent rise in the last year), thus reducing trip cost and time of local entrepreneurs and facilitating maintenance.

With a minimal environmental impact, the project has helped reduce 158 tons of CO_2 emissions per year and prevented 13 tons of uncontrolled battery waste. The estimated energy savings for all households was 216,133 soles per year (approximately EUR 53,365 per year). The EaaS model also favors environmental sustainability because acciona.org was responsible for the management of faulty systems, which were collected and sent to the provider of the SHS for adequate recycling of each component.

Fees have been made affordable, and the balance between revenue and costs ensures the continuity and economic sustainability of the project.

Despite the good results of the project, we observed a missed opportunity, because EaaS with prepaid modes may enable the use of information and communication technologies to improve fee collection and management, as well as the delivery of activation codes to users.

4. Discussion

Upon the analysis of the three case studies of rural electrification project, we can assess the impact of different configurations of the management model in the sustainability of the projects.

4.1. Social Sustainability

First, we observed a strong influence of the governance model in the social sustainability of the project, with better results in the projects where the number of agents involved in the operation of the project was higher. From the three projects under analysis, it is recommended to incorporate actors that (a) facilitate awareness and social sensibilization, (b) facilitate knowledge and technology transfer, and (c) know the local culture and customs [11,71]. For example, the incorporation of the CLCs in the latter two projects was so successful that CLCs have been added to the "Luz en Casa Cajamarca" project, which now has 12 active CLCs. The inclusion of entrepreneur profiles and CEFs in the projects improves the availability of maintenance, allows for training of local users, increases the participation of women in technical tasks and, in the end, facilitates the continuity of the project by generating a socially sustainable model.

The business model also has an effect on the social sustainability of the project. From the analysis of the three case studies, EaaS seems to offer better results in improving affordability, which is one of the main challenges in universal access to energy [43]. Besides, EaaS guarantees maintenance and replacement of faulty systems which, in turn, contributes to continued use and (again) to universal access because repairs do not entail additional cost for end users [77].

Funding and subsidization are also key for social sustainability. Both are heavily dependent on the agents involved in the project (states, regulators, and policymakers) and the resulting business model [79,80]. For example, only after the negotiations of acciona.org in Peru it was possible to create a regulated EaaS tariff for photovoltaic systems, which in turn made it possible to subsidize the fee and improve affordability of the systems.

4.2. Environmental Sustainability

In all three cases the results were similar, a result consistent with the use of the same technological model in the three projects (standalone systems using non-conventional or renewable sources). The positive results confirm previous literature, which identifies this kind of systems as the most adequate choice in rural electrification projects because they can reach remote and disperse communities, have high reliability and provide a more stable access to energy that does not depend on conventional grids nor requires complex infrastructure [55,81,82].

However, the use of systems that have a limited service life (mainly because of the batteries) requires the establishment of protocols to facilitate recycling of the different elements of the SHS, which otherwise would generate toxic waste and damage to the ecosystems [43]. Current trends in rural electrification assess whether it is possible to use fewer batteries to reduce the waste generated by SHS [82] by using independent micro-grids that rely on hybrid sources (e.g., solar and diesel) and require much lower battery capacity [69]. For instance, the acciona.org foundation is currently piloting a project in Copal Urco (Peru) to validate the sustainability of the technological model with hybrid sources (using diesel only as a backup source of energy generation).

4.3. Economic Sustainability

Economic sustainability is affected by the three main components of the model, as every aspect had a direct impact on the total costs and profitability of the project. First, the use of standalone systems has lower initial and infrastructure deployment costs, which favors economic sustainability [82]. Second, multi-agent governance models also have a positive effect on the economic sustainability of the projects; for instance, when the project incorporates the CLCs, maintenance costs are reduced due to the fact of less frequent trips and higher repair rates [79]. Third, projects operated as EaaS achieve a balance between revenue and costs that facilitates economic sustainability [81], even though profitability is only possible when a regulated tariff and subsidy are in place. This seems to suggest that fee-for-service models (both for system acquisition and maintenance) offer better results regarding economic sustainability.

5. Conclusions

The first part of this study showed a great variety of possible configurations of the management model in rural electrification projects. From a review of the literature, we elaborated a model that showed the different elements of the management model with three main components: governance, technological and business models. The governance model included all aspects relative to the actors involved in the project: owners/promoters or operators and their relationship with other agents, such as financers, regulators, academic institutions, and the communities and users that gain access to energy. The technological model considers choices in the technology based on the location of the communities, their dispersion, proximity to an existing grid, and available sources of energy generation. The business model includes how the systems are acquired and owned, maintenance costs, and the type of contract for service provision.

Our review highlights the concerns of rural electrification project promoters about achieving sustainability and affordability of the service to provide effective universal access while considering the diversity of each context that requires flexible and adaptable solutions. It is very complex to make decisions about the management model that improve the three dimensions of sustainability (social, environmental, and economic) because, most often, economic sustainability (namely, the profitability of the project) becomes the most relevant variable. It is not rare to observe decisions that improve the profitability but at the expense of affordability for end users.

Our analysis of the configurations of the management model of rural electrification projects identified 16 elements and their impact on the dimensions of sustainability. From the analysis, we observed that the environmental sustainability was mostly dependent on the technological model, but the business model had the higher impact on the social and economic sustainability of the project. The analysis of the three case studies under the lens of the management model and its impact on the sustainability of the project facilitated the identification of the strengths, weaknesses and areas of improvement of each project.

The main finding of the study is the key role of the business model and the collaboration between the agents involved in the sustainability of the projects. The choice of the business model is critical, and the analysis showed that fee-for-service models seem more adequate to ensure sustainability of the project. Socially, it allows for affordability of the systems to users in extreme poverty, by combining the fees with subsidies. Economically, in combination with an adequate regulatory framework and subsidization, it facilitates profitability and reduces operation and maintenance costs notably.

Collaboration between agents is essential to achieve sustainability. The analysis of the case studies suggests that variety of roles is important and that the communities and end users must have an active role in the project. In this sense, 5P and involvement of the communities in operational tasks seem to highly favor social sustainability.

The study is not exempt from limitations. Most notably, the three case studies had very similar configurations of the governance and technological models. While this choice allowed us to better understand the effect of the different configurations of the business model on the sustainability of rural electrification projects, a wider selection of case studies with different configurations of the governance and technological model are necessary to better understand the impact of each element of the management model on the different dimensions of sustainability.

Author Contributions: Conceptualization, L.D.-R.-C., S.I.-P. and Á.H.-G.; Methodology, L.D.-R.-C. and E.A.-N.; Validation, L.D.-R.-C., E.A.-N. and S.I.-P.; Formal analysis, L.D.-R.-C. and Á.H.-G.; Investigation, L.D.-R.-C., E.A.-N. and Á.H.-G.; Resources, L.D.-R.-C. and S.I.-P.; writing—original draft preparation, L.D.-R.-C. and Á.H.-G.; writing—review and editing, E.A.-N. and S.I.-P.; Visualization, L.D.-R.-C.; Supervision, S.I.-P.; Project administration, S.I.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank the acciona.org foundation for their help and support in the elaboration of this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. World Bank. Access to Energy is at the Heart of Development. 2018. Available online: https://www.worldbank.org/en/news/feature/2018/04/18/access-energy-sustainable-development-goal-7 (accessed on 15 October 2021).
2. Valentine, S.V. Emerging symbiosis: Renewable energy and energy security. *Renew. Sustain. Energy Rev.* **2011**, *15*, 4572–4578. [CrossRef]
3. United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development. 2015. Available online: https://undocs.org/A/RES/70/1 (accessed on 29 October 2021).
4. United Nations. *Report of the Secretary-General on SDG Progress 2019: Special Edition*; United Nations Publications: New York, NY, USA, 2019; pp. 1–64. Available online: https://sustainabledevelopment.un.org/content/documents/24978Report_of_the_SG_on_SDG_Progress_2019.pdf (accessed on 15 November 2021).
5. C. BP, "Foro de BP de Energía y Sostenibilidad," Interempresas. 2019. Available online: https://www.bp.com/es_es/spain/home/noticias/notas-de-prensa/foro-de-energia-y-sostenibilidad-bp---icai.html (accessed on 1 November 2021).
6. Franco, I.B.; Power, C.; Whereat, J. SDG 7 Affordable and clean energy. In *Actioning the Global Goals for Local Impact: Towards Sustainability Science, Policy, Education and Practice*; Franco, I.B., Chatterji, T., Derbyshire, E., Tracey, J., Eds.; Springer: Singapore, 2020; pp. 105–116.
7. Chu, S.; Majumdar, A. Opportunities and challenges for a sustainable energy future. *Nature* **2012**, *488*, 294–303. [CrossRef]
8. World Bank. The Welfare Impact of Rural Electrification: A Reassessment of the Costs and Benefits. 2008. Available online: http://lnweb90.worldbank.org/oed/oeddoclib.nsf/DocUNIDViewForJavaSearch/EDCCC33082FF8BEE852574EF006E5539/$file/rural_elec_full_eval.pdf (accessed on 21 October 2021).
9. Sovacool, B.K. The political economy of energy poverty: A review of key challenges. *Energy Sustain. Dev.* **2012**, *16*, 272–282. [CrossRef]
10. Del-Río-Carazo, L.; Iglesias-Pradas, S.; Acquila-Natale, E.; Martín-Fernández, J.G. Appropriate Technology for Access to Universal Basic Services: A Case Study on Basic Electricity Service Provision to Remote Communities in the Napo River Basin. *Sustainability* **2022**, *14*, 132. [CrossRef]
11. Chaurey, A.; Krithika, P.R.; Palit, D.; Rakesh, S.; Sovacool, B.K. New partnerships and business models for facilitating energy access. *Energy Policy* **2012**, *47* (Suppl. 1), 48–55. [CrossRef]
12. Schillebeeckx, S.J.D.; Parikh, P.; Bansal, R.; George, G. An integrated framework for rural electrification: Adopting a user-centric approach to business model development. *Energy Policy* **2012**, *48*, 687–697. [CrossRef]
13. Lillo, P.; Ferrer-Martí, L.; Juanpera, M. Strengthening the sustainability of rural electrification projects: Renewable energy, management models and energy transitions in Peru, Ecuador and Bolivia. *Energy Res. Soc. Sci.* **2021**, *80*, 102222. [CrossRef]
14. Eras-Almeida, A.A.; Fernández, M.; Eisman, J.; Martín, J.G.; Caamaño, E.; Egido-Aguilera, M.A. Lessons learned from rural electrification experiences with third generation solar home systems in Latin America: Case studies in Peru, Mexico, and Bolivia. *Sustainability* **2019**, *11*, 7139. [CrossRef]
15. World Bank. *Perú Rural Electrification*; ESMAP: Washington, DC, USA, 2001; Available online: https://openknowledge.worldbank.org/handle/10986/20300?locale-attribute=en (accessed on 3 October 2021).
16. Crousillat, E.; Hamilton, R.; Antmann, P. Addressing the Electricity Access Gap. Background Paper for the World Bank Group Energy Strategy. 2010. Available online: https://openknowledge.worldbank.org/bitstream/handle/10986/12530/690620ESW0whit0s0Gap0Final0Version.pdf?sequence=1&isAllowed=y (accessed on 4 November 2021).
17. Greeley, M. Rural energy technology assessment: A Sri Lankan case study. *World Dev.* **1986**, *14*, 1411–1421. [CrossRef]
18. Diouf, B.; Pode, R.; Osei, R. Initiative for 100% rural electrification in developing countries: Case study of Senegal. *Energy Policy* **2013**, *59*, 926–930. [CrossRef]
19. Herbert, C.; Phimister, E. Private sector-owned mini-grids and rural electrification: A case study of wind-power in Kenya's tea industry. *Energy Policy* **2019**, *132*, 1288–1297. [CrossRef]
20. Ilskog, E.; Kjellström, B. And then they lived sustainably ever after? Assessment of rural electrification cases by means of indicators. *Energy Policy* **2008**, *36*, 2008. [CrossRef]
21. Horiuchi, K. Diverse interpretations enabling the continuity of community renewable energy projects: A case study of a woody biomass project in rural area of Japan. *Local Econ.* **2018**, *33*, 2018. [CrossRef]
22. Yadoo, A.; Cruickshank, H. The value of cooperatives in rural electrification. *Energy Policy* **2010**, *38*, 2941–2947. [CrossRef]
23. Lillo, P.; Ferrer-Martí, L.; Boni, A.; Fernández-Baldor, Á. Assessing management models for off-grid renewable energy electrification projects using the Human Development approach: Case study in Peru. *Energy Sustain. Dev.* **2015**, *25*, 17–26. [CrossRef]

24. Madriz-Vargas, R.; Anna, B.; Muriel, W.; Alvarado, R.Y. Energy with development: 50 years' experience of community-driven rural electrification and future challenges for COOPEGUANACASTE in Costa Rica. In Proceedings of the Asia-Pacific Solar Research Conference, Canberra, Australia, 29 November–1 December 2016; pp. 1–12.
25. Judith, I.S.; Tarquino, M.; Cooper, D. Humanitarian Energy: Energy for Micro-Enterprises in Displacement Settings. 2020. Available online: https://endev.info/wp-content/uploads/2021/04/EnDev_Learning_and_Innovation_Humanitarian_Energy.pdf (accessed on 1 December 2021).
26. Gómez-Hernández, F.; Domenech, B.; Moreira, J.; Farrera, N.; López-González, A.; Ferrer-Martí, L. Comparative evaluation of rural electrification project plans: A case study in Mexico. *Energy Policy* **2019**, *129*, 23–33. [CrossRef]
27. Sovacool, B.K. Expanding renewable energy access with pro-poor public private partnerships in the developing world. *Energy Strateg. Rev.* **2013**, *1*, 181–192. [CrossRef]
28. IEA. Defining Energy Access: 2020 Methodology. 2020. Available online: https://www.iea.org/articles/defining-energy-access-2020-methodology (accessed on 20 October 2021).
29. Nagarjun, Y. Effectiveness of On-grid and Off-grid rural electrification approaches in India. In Proceedings of the 2015 International Conference on Sustainable Energy Engineering and Application (ICSEEA), Bandung, Indonesia, 5–7 October 2015. [CrossRef]
30. Peters, J.; Sievert, M. Impacts of rural electrification revisited: The African context. *Rev. Econ. Dev.* **2016**, *23*, 77–98. [CrossRef]
31. Barnes, D.F. Effective solutions for rural electrification in developing countries: Lessons from successful programs. *Curr. Opin. Environ. Sustain.* **2011**, *3*, 260–264. [CrossRef]
32. Kanase-Patil, A.B.; Saini, R.P.; Sharma, M.P. Integrated renewable energy systems for off grid rural electrification of remote area. *Renew. Energy* **2010**, *35*, 1342–1349. [CrossRef]
33. Hatziargyriou, N.; Asano, H.; Iravani, R.; Marnay, C. An Overview of Ongoing Research, Development, and Demonstration. *IEEE Power Energy Mag.* **2007**, 78. Available online: https://studylib.net/doc/18129150/microgrids--an-overview-of-ongoing-research--development-and (accessed on 29 September 2021). [CrossRef]
34. Gullberg, M.; Ilskog, E.; Katyega, M.; Kjellström, B. Village electrification technologies—An evaluation of photovoltaic cells and compact fluorescent lamps and their applicability in rural villages based on a Tanzanian case study. *Energy Policy* **2005**, *33*, 1287–1298. [CrossRef]
35. Kamalapur, G.D.; Udaykumar, R.Y. Electrification in rural areas of India and consideration of SHS. In Proceedings of the 2010 5th International Conference on Industrial and Information Systems, Mangalore, India, 29 July–1 August 2010. [CrossRef]
36. Mandelli, S.; Barbieri, J.; Mereu, R.; Colombo, E. Off-grid systems for rural electrification in developing countries: Definitions, classification and a comprehensive literature review. *Renew. Sustain. Energy Rev.* **2016**, *58*, 1621–1646. [CrossRef]
37. Chakrabarti, S.; Chakrabarti, S. Rural electrification programme with solar energy in remote region—A case study in an island. *Energy Policy* **2002**, *30*, 33–42. [CrossRef]
38. Bernardo, F.P.; Kilayko, G.U. Promoting rural energy technology: The case of gasifiers in the Philippines. *World Dev.* **1990**, *18*, 565–574. [CrossRef]
39. Hiremath, R.B.; Kumar, B.; Balachandra, P.; Ravindranath, N.H. Bottom-up approach for decentralised energy planning: Case study of Tumkur district in India. *Energy Policy* **2010**, *38*, 862–874. [CrossRef]
40. Wolde-Ghiorgis, W. Renewable energy for rural development in Ethiopia: The case for new energy policies and institutional reform. *Energy Policy* **2002**, *30*, 1095–1105. [CrossRef]
41. Akorede, M.F.; Hizam, H.; Pouresmaeil, E. Distributed energy resources and benefits to the environment. *Renew. Sustain. Energy Rev.* **2010**, *14*, 724–734. [CrossRef]
42. Lahimer, A.A.; Alghoul, M.A.; Yousif, F.; Razykov, T.M.; Amin, N.; Sopian, K. Research and development aspects on decentralized electrification options for rural household. *Renew. Sustain. Energy Rev.* **2013**, *24*, 314–324. [CrossRef]
43. Balachandra, P. Modern energy access to all in rural India: An integrated implementation strategy. *Energy Policy* **2011**, *39*, 7803–7814. [CrossRef]
44. Morris, E.; Winiecki, J.; Chowdhary, S.; Cortiglia, K. Using Microfinance to Expand Access to Energy Services: Summary of Findings. 2007. Available online: http://pdf.usaid.gov/pdf_docs/Pnadm641.pdf (accessed on 15 November 2021).
45. Ottinger, R.L.; Bowie, J. Innovative financing for renewable energy. *Energy Gov. Sustain.* **2016**, *32*, 125–148. [CrossRef]
46. Painuly, J.P.; Wohlgemuth, N. Renewable energy financing—What can we learn from experience in developing countries? *Energy Stud. Rev.* **2008**, *14*, 154–170. [CrossRef]
47. Williams, N.J.; Jaramillo, P.; Taneja, J.; Ustun, T.S. Enabling private sector investment in microgrid-based rural electrification in developing countries: A review. *Renew. Sustain. Energy Rev.* **2015**, *52*, 1268–1281. [CrossRef]
48. Ezor, Z. Power to the People: Rural Electrification in Uganda. ISP Collection. 2009, p. 35. Available online: http://digitalcollections.sit.edu/cgi/viewcontent.cgi?article=1675&context=isp_collection (accessed on 10 November 2021).
49. Palit, D. Solar energy programs for rural electrification: Experiences and lessons from South Asia. *Energy Sustain. Dev.* **2013**, *17*, 270–279. [CrossRef]
50. Lozano, L.; Taboada, E.B. Elucidating the challenges and risks of rural island electrification from the end-users' perspective: A case study in the Philippines. *Energy Policy* **2020**, *150*, 112143. [CrossRef]
51. Bhattacharjya, B.R.; Kakoty, S.K.; Singha, S. A feedback mechanism for appropriate technology development and dissemination: Case study approach. *Technol. Soc.* **2019**, *57*, 104–114. [CrossRef]

52. AI-Ali, S. Developing countries and technology transfer. *Int. J. Technol. Manag.* **1995**, *10*, 704–713.
53. Wensing, A.J.; Wensing, E.J.; Virgo, M. Towards a core curriculum for civic engagement on appropriate technology: Characterizing, optimizing and mobilizing youth community service learning. *Afr. J. Sci. Technol. Innov. Dev.* **2018**, *10*, 867–877. [CrossRef]
54. Gómez, M.F.; Silveira, S. Delivering off-grid electricity systems in the Brazilian Amazon. *Energy Sustain. Dev.* **2012**, *16*, 155–167. [CrossRef]
55. WCED. Our Common Future: Report of the World Commission on Environment and Development. *Med. War* **1987**, *5*, 17–25. [CrossRef]
56. Purvis, B.; Mao, Y.; Robinson, D. Three pillars of sustainability: In search of conceptual origins. *Sustain. Sci.* **2019**, *14*, 681–695. [CrossRef]
57. Gilbert, R.; Stevenson, D.; Girardet, H.; Stren, R. *Making Cities Work: Role of Local Authorities in the Urban Environment*; Routledge: London, UK, 1996.
58. Black, A.W. The Quest for Sustainable, Healthy Communities. *Aust. J. Environ. Educ.* **2004**, *20*, 33–44. [CrossRef]
59. Moldan, B.; Janoušková, S.; Hák, T. How to understand and measure environmental sustainability: Indicators and targets. *Ecol. Indic.* **2012**, *17*, 4–13. [CrossRef]
60. Giddings, B.; Hopwood, B.; O'Brien, G. Environment, Economy and Society: Fitting Them Together into Sustainable Development. *Sustain. Dev.* **2002**, *10*, 187–196. [CrossRef]
61. Martens, M.L.; Carvalho, M.M. Key factors of sustainability in project management context: A survey exploring the project managers' perspective. *Int. J. Proj. Manag.* **2017**, *35*, 1084–1102. [CrossRef]
62. Singh, R.K.; Murty, H.R.; Gupta, S.K.; Dikshit, A.K. An overview of sustainability assessment methodologies. *Ecol. Indic.* **2009**, *9*, 189–212. [CrossRef]
63. López-González, A.; Domenech, B.; Ferrer-Martí, L. Formative evaluation of sustainability in rural electrification programs from a management perspective: A case study from Venezuela. *Renew. Sustain. Energy Rev.* **2017**, *95*, 95–109. [CrossRef]
64. Mainali, B.; Silveira, S. Using a sustainability index to assess energy technologies for rural electrification. *Renew. Sustain. Energy Rev.* **2015**, *41*, 1351–1365. [CrossRef]
65. Boliko, C.M.; Ialnazov, D.S. An assessment of rural electrification projects in Kenya using a sustainability framework. *Energy Policy* **2019**, *133*, 110928. [CrossRef]
66. Brent, A.C.; Rogers, D.E. Renewable rural electrification: Sustainability assessment of mini-hybrid off-grid technological systems in the African context. *Renew. Energy* **2010**, *35*, 257–265. [CrossRef]
67. Bueno-Lopez, M.; Rodriguez-Sanchez, P.; Molinas, M. Sustainable model for rural electrification projects in Non-Interconnected Areas in Colombia. In Proceedings of the 2019 IEEE Global Humanitarian Technology Conference (GHTC), Seattle, WA, USA, 17–20 October 2019. [CrossRef]
68. Ilskog, E. *Rural Electrification Sustainability Indicators: Manual for Field Workers*; KTH University Press: Stockholm, Sweden, 2008; Available online: http://www.diva-portal.org/smash/record.jsf?pid=diva2:25019 (accessed on 16 November 2021).
69. López-González, A.; Domenech, B.; Ferrer-Martí, L. Sustainability evaluation of rural electrification in Cuba: From fossil fuels to modular photovoltaic systems: Case studies from sancti spiritus province. *Energies* **2021**, *14*, 2480. [CrossRef]
70. Jami, A.A.; Walsh, P.R. From consultation to collaboration: A participatory framework for positive community engagement with wind energy projects in Ontario, Canada. *Energy Res. Soc. Sci.* **2017**, *27*, 14–24. [CrossRef]
71. INEI. Status of the Peruvian Population. 2020. Available online: https://www.inei.gob.pe/estadisticas/indice-tematico/population/ (accessed on 20 June 2021).
72. Falcón-Roque, E.J.; Martín, F.M.; Castaño, C.P.; Domínguez-Dafauce, L.C.; Flores, F.J.B. Energy planning model with renewable energy using optimization multicriteria techniques for isolated rural communities: Cajamarca province, Peru. *J. Renew. Sustain. Energy* **2017**, *9*, 065903. [CrossRef]
73. Narayan, N.; Chamseddine, A.; Vega-Garita, V.; Qin, Z.; Popovic-Gerber, J.; Bauer, P.; Zeman, M. Exploring the boundaries of Solar Home Systems (SHS) for off-grid electrification: Optimal SHS sizing for the multi-tier framework for household electricity access. *Appl. Energy* **2018**, *240*, 907–917. [CrossRef]
74. Fernandez-Fuentes, M.H.; Eras-Almeida, A.A.; Egido-Aguilera, M.A. Characterization of technological innovations in photovoltaic rural electrification, based on the experiences of Bolivia, Peru, and Argentina: Third generation solar home systems. *Sustainability* **2021**, *13*, 3032. [CrossRef]
75. Instituto Nacional de Estadística y Geografía INEGI. Acceso a Electricidad México. 2010. Available online: https://www.inegi.org.mx/programas/encevi/2018/ (accessed on 20 October 2021).
76. Podder, S.; Khan, M.Z.R. Comparison of lead acid and Li-ion battery in solar home system of Bangladesh. In Proceedings of the 2016 5th International Conference of Informatics, Electronics and Vision, ICIEV, Dhaka, Bangladesh, 13–14 May 2016; pp. 434–438. [CrossRef]
77. Yadav, P.; Heynen, A.P.; Palit, D. Pay-As-You-Go financing: A model for viable and widespread deployment of solar home systems in rural India. *Energy Sustain. Dev.* **2019**, *48*, 139–153. [CrossRef]
78. IEA. Financing Mechanisms for Solar Home Systems in Developing Countries. The Role of Financing in The Dissemination Process. 2003. Available online: https://iea-pvps.org/wp-content/uploads/2020/01/rep9_01.pdf (accessed on 28 November 2021).
79. Lemaire, X. Fee-for-service companies for rural electrification with photovoltaic systems: The case of Zambia. *Energy Sustain. Dev.* **2009**, *13*, 18–23. [CrossRef]

80. Baurzhan, S.; Jenkins, G.P. Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries? *Renew. Sustain. Energy Rev.* **2016**, *60*, 1405–1418. [CrossRef]
81. Liu, Y.; Yu, S.; Zhu, Y.; Wang, D.; Liu, J. Modeling, planning, application and management of energy systems for isolated areas: A review. *Renew. Sustain. Energy Rev.* **2018**, *82*, 460–470. [CrossRef]
82. Mamaghani, A.H.; Escandon, S.A.A.; Najafi, B.; Shirazi, A.; Rinaldi, F. Techno-economic feasibility of photovoltaic, wind, diesel and hybrid electrification systems for off-grid rural electrification in Colombia. *Renew. Energy* **2016**, *97*, 293–305. [CrossRef]

energies

Article

Appraisal Modeling for FSRU Greenfield Energy Projects

Dimitrios Dimitriou * and Panagiotis Zeimpekis

Department of Economics, Democritus University of Thrace, 69100 Komotini, Greece; panazeib@econ.duth.gr
* Correspondence: ddimitri@econ.duth.gr

Abstract: Floating storage and regasification units (FSRU) provide a flexible and competitive energy distribution option when it comes to the regasification of liquefied natural gas (LNG). FSRU projects have become more and more popular, attracting the interest of investors, energy authorities, and governments; therefore, the project feasibility in terms of risks and profitability are a major concern. This paper deals with the appraisal of a greenfield LNG infrastructure project, where usually, decision complexity deals with the high number and different expectation of stakeholders, the capital-intensive financing nature, and the business risks in the project life cycle. Conventional wisdom is to provide a coherent, compact, and well-structured appraisal modelling framework, adjusted to FSRU technical, structural, and operational features on one hand; and business risks, long-term life cycle, and investment attractiveness on the other. Appraisal modelling structure and outputs are considered to provide key messages to the decisions involved and interested parties toward the project feasibility and the associated investment risks for the implementation of the FSRU project. The proposed modelling framework was applied to the Alexandroupolis FSRU project, where the first discussion was many years ago, but the existing conditions in the energy market are raising the interest for developing energy distribution facilities globally.

Keywords: FSRU; LNG; appraisal modeling; modeling energy project appraisal; economic assessment; project incentives; energy project accounting; greenfield project planning; project due-diligence

Citation: Dimitriou, D.; Zeimpekis, P. Appraisal Modeling for FSRU Greenfield Energy Projects. *Energies* **2022**, *15*, 3188. https://doi.org/10.3390/en15093188

Academic Editors: Bernard Ziębicki and Edyta Bielińska-Dusza

Received: 6 March 2022
Accepted: 21 April 2022
Published: 27 April 2022

1. Introduction

As the need for a more sustainable and decarbonized future is continuously growing [1], natural gas (NG) has become one of the main primary energy sources in the world, due to its environmentally friendly nature and its multiple uses across a number of sectors. In the European Union (EU), NG is mainly used to produce electricity and for heating purposes, but it can be expanded to new fields such as agriculture [2] and aviation [3], and it is the second most commonly used energy source, combining for 23.1% of total energy consumption for the year 2018 [4].

One of the biggest challenges in energy consumption that places such as Europe have faced is the extremely high dependency in NG imports. Since the only EU members which have facilities for the production of NG are Norway and the Netherlands, the import dependency of NG has reached almost 90% for 2019, with Russia being the main supplier, providing 41.3% of the NG used in European Union countries for 2019 [4], although the NG flow from Russia to the European Union is projected to significantly decrease in the coming years [5,6]. This relationship strongly affects the European gas market [7,8]. The EU, in need of securing its energy stability and primary sources availability, set the diversification of energy sources to supply one of the main aims of its energy policy [9].

For NG, this can be succeeded by Liquefied Natural Gas (LNG), which allows NG to be transported in large quantities all over the world [10], without the location-specific limitations that underground pipelines create. The traditional supply chain of LNG includes gas production, liquefaction, shipping, storage, and regasification [11]. LNG is a liquid state of natural gas which is cooled to below 113.1 K, and its volume is 600 times smaller than that of NG [12]. Upon reaching its destination, LNG is reverted to natural gas at import terminals and distributed via pipelines to the final consumers [13,14]. The conversion from the liquid phase of LNG to gas can be implemented using onshore facilities or regasification ships moored at specially designed docks for this purpose, allocating significantly fewer capital expenses than the onshore terminals [15,16]. In the last case, the terminal is based on a Floating Storage and Regasification Unit (FSRU) permanently moored at the jetty and periodically supplied by an LNG carrier. FSRU, for small- and mid-sized markets, typically offer a more cost-effective, faster, and flexible means to bring natural gas to consumers compared to shore-based terminals [17–19]. In 2020, there were 34 FSRU operating, and 12 more are under construction [20]. Most of these stations are located in Eastern Asia and America. Europe are currently operating only five FSRU: in Toscana, Italy; in Klaipeda, Lithuania; in Aliaga and Dortyol, Turkey; whereas the most recently constructed FSRU is the one in Krk, Croatia, which started operation in 2021 [21,22]. Moreover, the only FSRU that is currently constructing in Europe is in Cyprus [21].

Greece is one of the EU members that is most dependent in NG imports, since it imports the 100% of its needs. The energy transportation to renewable sources has turned NG to one of the main energy sources used in Greece, increasing the usage from 3.500 mil NM3 in 2009 to almost 5000 mil NM3 in 2019 [23]. The need for the diversification of sources has also changed the ways that Greece imports its NG quantities, and increased the needs for LNG. The LNG supplied to Greece for 2019 was 47.6% of the whole NG imported, whereas it was only 19.7% in 2018 [23]. According to Greece's yearly National Natural Gas System (NNGS) allocation data, the LNG was supplied mainly from USA (48.26%) and Qatar (22.36%) [24].

While the demand is growing so fast, the necessity for more expanded and well-developed natural gas distribution infrastructure is rising as well. Greece currently disposes an onshore terminal facility for the regasification process in Agia Triada, next to Athens. Besides this, a new energy projects initiative with the approval of the government decided on the construction of a new FSRU station at the Alexandroupolis sea area, located in the northern part of Greece.

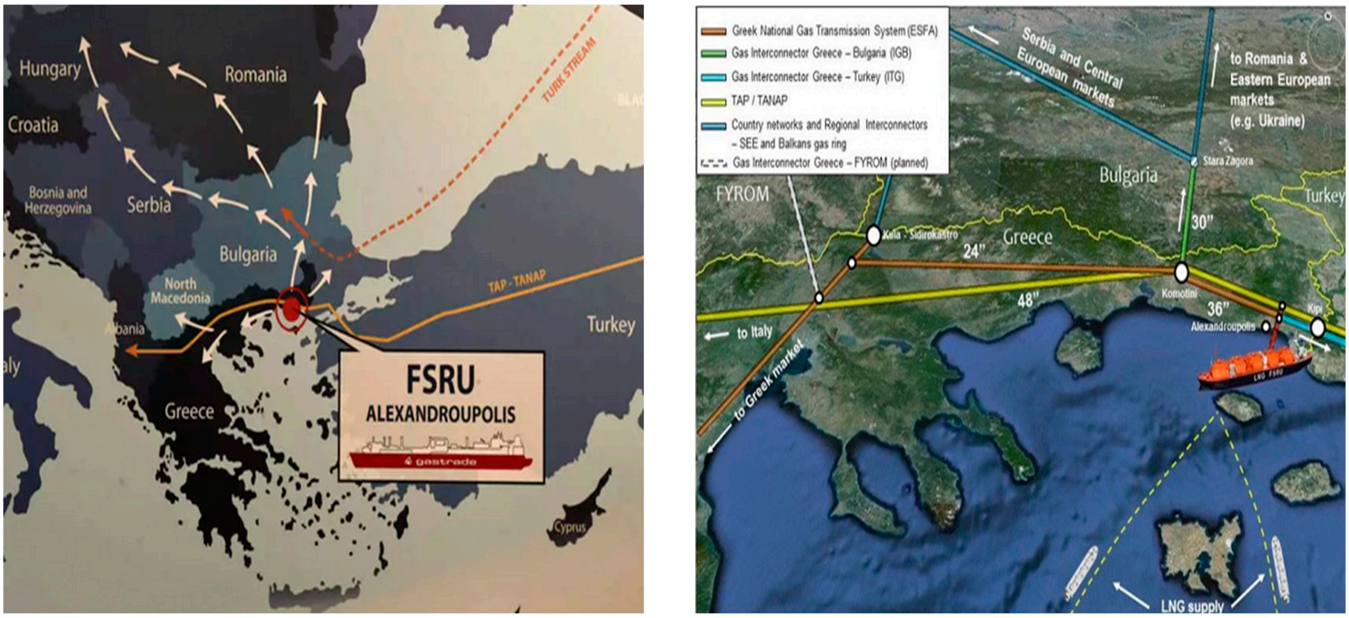
This paper sets a comprehensive dynamic framework to evaluate the feasibility and economic footprint for the development of a new FSRU Station, considering the energy market characteristics, the project development phases, and the financing volatility. By a systemic approach, the appraisal modelling is presented, and it is applied to the Alexandroupolis city FSRU project in Greece. The output sensitivity, reviewed based on the FSRU station usage rate, linked the project viability with the energy demand risks. Additionally, the analysis provides key messages to planners and decision-makers regarding the incentives towards FSRU project implementation, promoting risk-sharing measures towards investment attractiveness.

This paper's novelty is to provide a coherent FSRU appraisal modelling structure adjusted for a new energy infrastructure project with a long-term payback period and high volatile business environment, which may support planners, economists, and decision-makers to illustrate conclusions on project feasibility, compare it with other projects, and apply it to similar cases. The analysis output sensitivity, reviewed based on the energy FSRU station usage rate, linked the project viability with the energy demand risks. Additionally, the analysis provides key messages to planners and decision-makers regarding the incentives towards FSRU project implementation, promoting risk-sharing measures towards investment attractiveness. This paper's novelty is to provide a coherent FSRU appraisal modelling structure adjusted for a new energy infrastructure project with a long-term payback period and high volatile business environment, which may support planners, economists, and decision-makers to illustrate conclusions on project feasibility, compare it with other projects, and apply it to similar cases.

2. Alexandroupolis FSRU Station Features

The Alexandroupolis, Greece, FSRU Station is planned to be constructed in the sea area southwest of the town of Alexandroupolis at a distance of 17.6 km from Alexandroupolis

Port (Figure 1). The floating unit is planned to have four LNG storage tanks with a total capacity of up to 170,000 cubic meters. The dimensions of the floating unit will be approximately 300 m in length (LOA), 32.5 m in breadth, and 26.5 m in height (depth to upper deck) [25].



(**a**) (**b**)

Figure 1. (**a**) Alexandroupolis FSRU interconnections [25]; (**b**) Alexandroupolis FSRU location [25].

The NG after the regasification process will be transferred to the Greek National NG System (NNGS) via a 24 km subsea pipeline, which will be laid on a sea depth over 15 m, and a 4 km, 30″, and 100 bar operating pressure onshore underground pipeline [25]. A new Metering Station is constructed to act as the connection point with the (NNGS).

The key activities for the new FSRU Station are:

- Feed directly into the Greek NG Transmission System (NNGS) to supply the Greek market.
- Provide direct access to the Bulgarian market via the under-construction Greek–Bulgarian Interconnector Pipeline (IGB) and through the Bulgarian pipelines to the Balkan region, Hungary and Eastern Europe markets.
- Supply the Turkish market via reverse flow functionality of the existing Turkey–Greece Interconnection Pipeline.
- Connect with the European South Corridor gas projects such as TAP.

The exact location of the station and the interconnections with the neighboring countries are presented in Figure 1.

3. FSRU Appraisal Modelling Framework

The appraisal modelling framework was developed by a breakdown of the key unit cost in the project lifecycle. The FSRU project characteristics taken into consideration for the definition the project unit cost distinguished the lifecycle in two time periods: the construction and the operation. In the operation period, the energy market volatility has taken into consideration the promotion of a dynamic formulation of the equations. In the following part, the modelling structure and the associated explanations are expressed.

3.1. Initial Capital Cost

The total capital cost required during the construction period includes the construction cost and the project implementation cost. The construction cost includes the FSRU Vessel purchase, which is usually the larger unit cost; the mooring of the Vessel; the construction of subsea and inland pipelines to transfer the NG to the larger transmission pipeline; and the cost of other equipment needed for the FSRU Station operation. Project implementation cost is considered the cost of the project team, management support services, the specialists, and consultants prior to the final investment decision; and the administrative costs, such as the contract preparation, the procurement, the permits, and the licenses from authorities.

Therefore, the project capital cost calculated by the following equation:

$$\text{ICC} = \text{Con} + \text{Own} + \text{Cont} \tag{1}$$

where,

ICC is the total Initial Capital Cost during the construction period;
Con is the Construction Cost;
Own is the project implementation costs undertaken by the FSRU project shareholders; and
Cont is the cost of any contingency that may happen.

3.2. Financing

In such a large investment, usually, the funding for the capital costs is undertaken either by the shareholders equity or by a project financing tool, such as bank loan, bond issue, or by a combination of shareholders and bank or market funds. Therefore, the total capital cost is:

$$\text{ICC} = \text{E} + \text{B} \tag{2}$$

where,

ICC is the total Initial Capital Costs during the construction period (see Equation (1));
E is the Shareholders Equity; and
B is the funds retrieved by a bank loan.

In case of a bank loan, the annual installment is determined by the following equation:

$$L_i = \frac{B * \ i_{RL} * (1 + i_{RL})^n}{(1 + i_{RL})^n - 1} \tag{3}$$

where, $i \in N$ and $1 \leq i \leq n$;

L_i is the annual loan installment in the year i;
B is the total funds retrieved by the bank loan;
i_{RL} is the loan interest rate; and
n is the years that the loan must be paid.

For the project financing lifecycle, the total loan cost is:

$$TL = \sum_{i=1}^{n} L_i \tag{4}$$

where, $i \in N$ and $1 \leq i \leq n$;

TL is the total loan cost during the whole period of the loan payment;
L_i is the annual loan installment in the year I (see Equation (3)); and
n is the years that the loan must be paid.

The annual loan installment includes both an interest and a principal amount. The interest amount is used in order to calculate the net income before taxes, so it must be estimated. The mathematic formula is given below:

$$L_{Ii} = L_i + (1 + i_{RL})^{i-1} * (B * i_{RL} - L_i) \tag{5}$$

where, $i \in N$ and $1 \leq i \leq n$;

L_{Ii} is the interest paid amount of the loan that is given during the year i;
L_i is the annual loan installment in the year I (see Equation (3));

B is the total funds retrieved by the bank loan (see Equation (2)); and
i_{RL} is the loan interest rate.

The principal paid amount in each annual installment is given by the following formula:

$$L_{pi} = L_i - L_{Ii} \tag{6}$$

where, $i \in N$ and $1 \leq i \leq n$;

L_{Pi} is the principal paid amount of the loan that is given during the year i;
L_{Ii} is the interest paid amount of the loan that is given during the year i (see Equation (5));
L_i is the annual loan installment in the year i (see Equation (3)).

3.3. Sales Income

The FSRU revenue streams deal with the regasification services that it provides. The extent of the sales income depends on the capacity of the FSRU's Vessel, due to the fact that the larger the storages are, the more LNG quantity can be degasified. Moreover, it depends on the quantity of the LNG carriers that use the facilities, which, in this analysis, is called "usage rate" of the Station, and is expressed as a percentage of the Station's yearly usage. Finally, it depends on the tariff that the Station charges its customers for the regasification services, and is usually expressed on price per normalized cubic meter (Nm^3). The Station will operate for (T) years, and given the above, the annual Sales income is given by:

$$RV_i = C_V * uf_i * TR_i \tag{7}$$

where, $i \in N$ and $1 \leq i \leq T$;

T is the years of operation of the FSRU Station;
RV_i is the annual revenue for the operation year i;
C_V is the total annual capacity of the Vessel in Nm^3;
uf_i is the usage rate of the FSRU Station for the operation year i;
TR_i is the tariff price charged per normalized cubic meter or LNG for the operation year i.

The total sales income for the whole operation period of the Station is:

$$R = \sum_{i=1}^{T} RV_i \tag{8}$$

where, $i \in N$ and $1 \leq i \leq T$;

RV_i is the annual revenue for the operation year i.

3.4. Operating and Capital Costs

The main operational cost covers the personnel working in the Station, usually around 120 persons, who work on the onshore facilities, in the marine section for the transportation of the personnel, in the operating department, and the maintenance department of the FSRU. Furthermore, the operational costs include the power and steam generation needed for the FSRU's equipment; the maintenance and inspection costs; the underwater inspections; the materials, chemicals, and spare part supply; the insurance; the harbor fees; the service boat maintenance; the dredging inspection; and finally, the head office support to the operations.

The operational cost for the power and steam generation during the regasification process is estimated according to the below formula:

$$PowCost_i = PowCost_Y * uf_i \tag{9}$$

where, $i \in N$ and $1 \leq i \leq T$;

$PowCost_i$ is the power and steam generation cost for the operation year i;
$PowCost_Y$ is the power and steam generation cost if the usage rate was 100%; and
uf_i is the usage rate of the FSRU Station for the operation year i.

In addition, the operational costs depending on the usage rate of the Station are essential to take into consideration. To quantify the variable cost that is related to the usage rate of the FSRU, it is estimated by correlating it with the operational expenses when the usage rate is 100%, and the usage rate through a variable named b_i. Respectively, the fixed costs to the operational costs of 100% usage rate use a variable named a_i. Therefore, the fixed and variable costs, as well as the operational costs given from the below group of equations:

$$FC_i = a_i * OPEX_{100\%} \quad (10)$$

$$VC_i = b_i * OPEX_{100\%} * uf_i \quad (11)$$

$$OPEX_i = FC_i + VC_i \quad (12)$$

where, $i \in N$ and $1 \leq i \leq T$;

$OPEX_{100\%}$ is the annual operating cost for 100% usage rate of the FSRU Station;
$OPEX_i$ is the annual operational cost except from the LNG consumption cost for the operation year i;
FC_i is the fixed cost for the operation year i;
VC_i is the variable cost, for the operation year i;
a_i and b_i are numbers that correlate the fixed and variable costs with the operational costs, $a_i, b_i \in R$, $0 < a_i < 1$, $0 < b_i < 1$, and $a_i + b_i = 1$.

The annual capital expenditures include all the costs related to the upgrade of the existing facilities and equipment that are necessary for the operation of the FSRU. Furthermore, they include the costs of acquiring new assets, and research and development (R&D) costs. The annual capital costs are usually correlated to the initial investment cost, and can de expressed as:

$$CAPEX_i = c_i * ICC \quad (13)$$

where, $i \in N$ and $1 \leq i \leq T$;

$CAPEX_i$ is the capital expenditures for the operation year i;
c_i is a number that correlates the annual capital expenditures with the capital costs of the construction period, $c_i \in R$, $0 < c_i < 1$.

3.5. Depreciation and Amortization

It is important to analyze and distinguish the capital expenditures from the operating cost, because the first is depreciated and reduces the final payable tax. Moreover, the depreciation depicts the value of the project assets over time, providing the market value of the project. To calculate the depreciation, we have to add the depreciation of the initial capital cost to the depreciation of the annual capital expenditures produced every operating year. This means that to estimate the depreciation cost for the 10th year of operation, the following are added: the depreciation of initial capital cost during the 10th year, the depreciation of capital expenditure of 1st year of operation during the 10th year, the depreciation of capital expenditure of 2nd year of operation during the 10th year, etc. In real-life applications, it uses methods to account for depreciation, such as straight line depreciation, declining balance, double declining balance, sum of the year's digits, and units of production. In this analysis, the straight line method approach is selected, because the project production ability is not stabile over time, and it provides more accuracy for a long lifecycle project with a long payback period.

Using the straight line method, the salvage value of the asset after the depreciation period and the depreciation rate must be set according to accounting norms and the used materials and equipment in the project. In this analysis, the depreciation ratio received was stable over time, and it covered the overall project lifecycle. This means that the depreciation amount for each infrastructure and equipment unit cost will be stable for all of the operating period, except from the last year that it can get a lower price, until it matches its salvage value.

Therefore, the depreciation for the construction cost is estimated by:

$$\text{If } i = 1, \text{ then } D_{(i)Con} = d_{Con} * (Con - SAL_{Con}) \tag{14a}$$

$$\begin{gathered}\text{If } i > 1 \text{ and } REMV_{(i-1)Con} - D_{(i-1)Con} > SAL_{Con}, \text{ then} \\ D_{(i)Con} = d_{Con} * (Con - SAL_{Con})\end{gathered} \tag{14b}$$

$$\begin{gathered}\text{If } i > 1 \text{ and } REMV_{(i-1)Con} - D_{(i-1)Con} \leq SAL_{Con}, \text{ then} \\ D_{(i)Con} = REMV_{(i-1)Con} - SAL_{Con}\end{gathered} \tag{14c}$$

where, $i \in N$ and $1 \leq i \leq T$;

$D_{(i)Con}$ is the depreciation amount of the initial construction capital cost for the operating year i;

d_{Con} is the depreciation rate, expressed as percentage (%) of the initial construction capital cost;

Con is the initial construction capital cost (see Equation (1));

SAL_{Con} is the salvage value of the initial construction capital cost; and

$REMV_{(i)Con}$ is the remaining value of the initial construction capital cost after depreciation in the operating year i, and is given by the below equation:

$$\begin{gathered}\text{If } Con - i * d_{Con} * (Con - SAL_{Con}) > SAL_{Con}, \text{ then} \\ REMV_{(i)Con} = Con - i * d_{Con} * (Con - SAL_{Con})\end{gathered} \tag{15a}$$

$$\begin{gathered}\text{If } Con - i * d_{Con} * (Con - SAL_{Con}) \leq SAL_{Con}, \text{ then} \\ REMV_{(i)Con} = SAL_{Con}\end{gathered} \tag{15b}$$

The depreciation amount for the capital expenditure costs produced during the (i) year of operation is calculated using the same logic as above, and given according to the following equations:

$$\text{If } i = j, \text{ then } D_{(i)CAPEX_j} = d_{CAPEX_j} * \left(CAPEX_j - SAL_{CAPEX_j}\right) \tag{16a}$$

$$\begin{gathered}\text{If } i > j \text{ and } REMV_{(i-1)CAPEX_j} - D_{(i-1)CAPEX_j} > SAL_{CAPEX_j}, \text{ then} \\ D_{(i)CAPEX_j} = d_{CAPEX_j} * \left(CAPEX_j - SAL_{CAPEX_j}\right)\end{gathered} \tag{16b}$$

$$\begin{gathered}\text{If } i > j \text{ and } REMV_{(i-1)CAPEX_j} - D_{(i-1)CAPEX_j} \leq SAL_{CAPEX_j}, \text{ then} \\ D_{(i)CAPEX_j} = REMV_{(i-1)CAPEX_j} - SAL_{CAPEX_j}\end{gathered} \tag{16c}$$

where, $i \in N$, $1 \leq i \leq T$, $j \in N$, $1 \leq j \leq T$, and $i \geq j$;

$D_{(i)CAPEX_j}$ is the depreciation amount for operating year i of the capital cost that was produced during operating period j, $i \geq j$, $i \in N$, $j \in N$;

d_{CAPEX_j} is the depreciation rate of the capital cost that was produced during operating period j, $j \in N$;

SAL_{CAPEX_j} is the salvage value of the capital cost that was produced during operating period j, $j \in N$;

$REMV_{(i)CAPEX_j}$ is the remaining value of the capital cost that was produced during operating year j, after depreciating in the operating year i, and is given by the below equations:

$$\begin{gathered}\text{If } CAPEX_j - (i - j) * d_{CAPEX_j} * \left(CAPEX_j - SAL_{CAPEX_j}\right) > SAL_{CAPEX_j}, \text{ then} \\ REMV_{(i)Con} = CAPEX_j - (i - j) * d_{CAPEX_j} * \left(CAPEX_j - SAL_{CAPEX_j}\right)\end{gathered} \tag{17a}$$

$$\begin{gathered}\text{If } CAPEX_j - (i - j) * d_{CAPEX_j} * \left(CAPEX_j - SAL_{CAPEX_j}\right) \leq SAL_{CAPEX_j}, \text{ then} \\ REMV_{(i)Con} = SAL_{CAPEX_j}\end{gathered} \tag{17b}$$

Given the Equations (14) and (16), the depreciation amount for all capital costs, including initial capital costs and annual capital costs, for each operating year is expressed as:

$$D_i = D_{(i)Con} + \sum_{j=1}^{i} D_{(i)CAPEX_j} \tag{18}$$

where, $i \geq j$, $i \in N$, $1 \leq i \leq T$ $j \in N$, and $1 \leq j \leq T$.

Similarly, according to Equations (15) and (17), the remaining value after depreciation of the whole project's capital costs for each operating year can be expressed as:

$$REMV_i = REMV_{(i)Con} + \sum_{j=1}^{i} REMV_{(i)CAPEX_j} \tag{19}$$

The amortization consists of the loan's amortization and the intangible asset amortization. The loan's amortization is the interest-paid amount of the loan given using Equation (5). The amortization of the intangible assets is calculated in the same way used above for the calculation of depreciation. Finally, the amortization is expressed as follows:

$$A_i = L_{Ii} + A_{(i)Con} + \sum_{j=1}^{i} A_{(i)CAPEX_j} \tag{20}$$

where, $i \geq j$, $i \in N$, $1 \leq i \leq T$ $j \in N$, and $1 \leq j \leq T$.

3.6. Income Statement

Taking into consideration the sales revenues (Equation (7)), the operating (Equation (12)) and capital expenditures (Equation (13)), the interests (Equation (5)), the depreciation (Equation (18)), and the amortization (Equation (20)), the earnings before taxes (EBT) for the operating year i are given by:

$$EBT_i = RV_i - PowCost_i - OPEX_i - D_i - A_i - LI_i \tag{21}$$

where, $i \in N$, $1 \leq i \leq T$.

For the EBT of each year, a certain tax applied, being set by the government and local authorities. The tax is applied only when the EBT is higher than 0, and the company has earnings in that specific tax year:

$$TAXES_i = \begin{cases} tax_i * EBT_i, \text{ if } EBT_i > 0 \\ 0, \text{ if } EBT_i \leq 0 \end{cases} \tag{22}$$

where, $i \in N$, $1 \leq i \leq T$;

$TAXES_i$ is the tax expense for the operating year i;

tax_i is the tax percentage set by the government for operating year i.

The net earnings (NE) for each year reflect the earnings of the organization after the imposed taxes, and it is an important element to evaluate the profitability of an investment because it takes into account all revenues and expenses the company has. For the operating year i, the net earnings are calculated as follows:

$$NE_i = EBT_i - TAXES_i \tag{23}$$

where $i \in N$, $1 \leq i \leq T$.

3.7. Cash Flow

The total cash inflows for the FSRU Station of the current study come only from the revenues we have calculated from Equation (7). As such, total cash inflows are:

$$CFI_i = RV_i \tag{24}$$

where CFI_i is the cash inflows for the operating year i, $i \in N$.

The total cash outflows come from the power generation costs during the regasification process (see Equation (9)), the operating (see Equation (12)) and capital expenses (see Equation (13)), and the interest (see Equation (4)) and the taxes expenses (see Equation (22)), and they are calculated by the following formula:

$$CFO_i = PowCost_i + OPEX_i + CAPEX_i + D_i + A_i + L_i + TAXES_i \quad (25)$$

where CFO_i is the cash outflows for the operating year i, ieN.

From the above Equations (24) and (25), the total cash flows are expressed by:

$$CF_i = CFI_i - CFO_i \quad (26)$$

where CF_i is the cash flows for the operating year i, ieN.

3.8. NPV and IRR

To be able to conduct an economic assessment of the project, there are several financial techniques. The most common methods include Break Even Point Analysis, Payback Time Period, Net Present Value (NPV), and Internal Rate of Return (IRR). In the present paper, we have conducted the NPV and IRR analysis in order to assess the results of our study. The main purpose of the financial analysis is to use the project cash flow forecasts to calculate suitable net return indicators [26–29].

To calculate the NPV, we use the cash flows for each operating year, and then discount the stream back to the present time period. The formula for deriving NPV is:

$$NPV = (-ICC) + \sum_{i=1}^{T} \frac{CF_i}{(1 + DR)^i} \quad (27)$$

where $i \in N\ 1 \leq j \leq T$; and

DR is the discount rate.

Financial sustainability is ensured if NPV of cumulated cash flow is positive for all the years considered [26].

For the IRR calculation, in Equation (27), we set NPV equal to zero and DR=IRR. Then, we can solve to find the IRR:

$$NPV = (-ICC) + \sum_{i=1}^{T} \frac{CF_i}{(1 + IRR)^i} = 0 \quad (28)$$

The IRR should match a certain price that is set by the shareholders in order to assess positively the investment, and, at least, should be greater than the discount rate.

3.9. Tax Incentives

In this section, the key question is if, and in what level of capitals, the state's authorities could promote the investment by offering tax benefits and making the investment more attractive to potential investors. Large infrastructure projects develop, assess, and support activities providing a positive contribution to the regional economy [26–28]. This can boost the socioeconomic development of regional and remote areas of a state, such as Alexandroupolis [29–31]. Therefore, the state would favor to promote and facilitate the construction of such a project.

The methodology used includes estimating the economic benefits that the state will indirectly gain from the operation of the Station. "Indirectly" benefits include all the other sources of income the FSRU will generate, except from the taxes that will be paid to the state at the end of every tax year. Such sources can be the taxation of works and activities related to the Station, the taxation of the employees' salaries, and others. In this analysis, firstly, these activities will be pointed out, and then, the total turnover of each activity will be estimated, and the taxation incomes will be found out. Finally, these profits that the state will gain from the FSRU's operation can be given to the FSRU as tax reliefs.

Specifically, the state will gain tax incomes during the construction period. For the construction of the Station's heavy equipment, such as the FSRU vessel or the NG pipelines, these will be supplied and imported to the country, and works and services will be performed, such as the construction of the pipeline, the dredging of the vessel, the Project's reporting, and others. All of these supplies and works will be taxed by the government. Furthermore, extra jobs will be created, and the state will be benefited by the taxation on their salaries.

During the operation period, the Station shall employ around 120 people personnel. The state gains taxes from the salaries that the FSRU pays to these employees. These taxes come not only from the direct taxation, but also from the fact that these people will spend their wages, and they will be taxed for these purchases.

Moreover, during the operating period, each year, the Station generates operating and capital expenditures, which concern the supply of goods and services which include taxes to the state. These expenses for each operating year i are the sum of $OPEX_i$ and $CAPEX_i$ (Equations (12) and (13)) minus the wages of the personnel mentioned above, and expressed from the following formula:

$$FSRUEXP_i = OPEX_i + CAPEX_i - Sal_i \tag{29}$$

where, $i \in n$, $1 \leq i \leq T$;

$FSRUEXP_i$ is the total turnover generated by the annual operating and capital costs of the FSRU for the operating year i;
$OPEX_i$ is the operating expenses during operating year i;
$CAPEX_i$ is the capital costs during operating year i;
Sal_i is the total salaries paid to the FSRU personnel during operating year i.

Finally, the Station produces some extra activities. An FSRU needs, for its maintenance and inspection, someone with technical expertise, who will probably need to come from other areas of Greece or even from abroad. These people will generate turnover by their transport, food, and accommodation expenses. Moreover, the regasification process usually lasts almost a day. This means that the LNG carriers' personnel (around 20 people) will stay for one day in the town of Alexandroupolis, spending money on food, coffee, gifts, and others. This tax income depends on the usage rate of the FSRU.

The tax income from all the above-mentioned cases can be expressed by the following equation:

$$STATEINC = Con * TAX_{ICC} + \sum_{i=1}^{T} [Sal_i * Tax_{Sali} + FSRUEXP_i * Tax_{FSRUEXPi} + Local_i * Tax_{Locali}] \tag{30}$$

where, $i \in N$, $1 \leq i \leq T$;

STATEINC is the total income from taxes generated from FSRU during the construction and operating period, without taking into account the taxes of FSRU;
TAX_{ICC} is the total tax applied to the income generated during the construction period;
Sal_i is the total yearly wages paid to the FSRU personnel during the operating year i;
Tax_{Sali} is the total tax applied to the salaries of the FSRU personnel for operating year i;
$Tax_{FSRUEXPi}$ is the tax applied to the operating and capital expenditures of the FSRU during the operating year i;
$Local_i$ is the total income generated for local society during operating year i;
Tax_{Locali} is the tax applied to the income for local society during operating year i.

After estimating the total income from the taxes, the state may decide whether it is in its interest to proceed with offering tax incentives. Then, the taxes of the FSRU are given by Equation (22), modified according to the below formula:

$$\text{TAXES}_\text{i} = \begin{cases} \text{tax}_\text{i} * \text{EBT}_\text{i} - \text{TAXrelief}_\text{i},\ \text{if EBT}_\text{i} > 0 \\ 0,\ \text{if EBT}_\text{i} \leq 0 \end{cases} \quad (31)$$

where, $\text{TAXrelief}_\text{i}$ is the tax relief that the state offers for operating year i.

Finally, the NE, NPV, and IRR are re-adjusted according to Equation (31).

4. Numerical Application Results

Based on above modelling framework for the evaluation of an FSRU Project, the numerical application deals with the development of the new Alexandroupolis FSRU Project. The primary referenced data that relate to the specific characteristics of a FSRU Station, such as basic operating and construction costs, are retrieved from "The Outlook for Floating Storage and Regasification Units (FSRUs)" and "Floating LNG Update-Liquefaction and Import Terminals", both published by the Oxford University for Energy Studies [32,33]. We have also used data from the operating OLT Offshore LNG Toscana FSRU Station located in Toscana, Italy [34].

Subsequently, a sensitivity analysis subject to the FSRU usage rate has to be conducted supporting decisions regarding the authorities' taxation, and in what range a tax reduction scheme or mitigation policies could be increase the capital leverage, providing a win–win risk mitigation scheme between authorities and private funds.

4.1. Economic Assessment of the Alexandroupolis FSRU Station

Economic analysis provides decision-makers with a way of assessing the overall value of a project, including the financial viability and the investment's likely productivity and effectiveness indexes [29,30].

The FSRU of Alexandroupolis is the first FSRU Station being constructed in the Greece territory, characterized as a totally greenfield project, and there are not existing baseline scenarios or data to be used for the economic analysis. The available data have already been addressed, mainly related to FSRU key operational characteristics, such as the Vessel's capacity. Therefore, the analysis structure developed by analyzing all the necessary factors and rates is necessary to be taken into consideration to assess the economic output of the project. For the readers and users of the proposed methodology framework, the formulation provides a dynamic modelling formulation structure, where key assessment variables are adjusted over the project lifecycle, the technical features, the financial market conditions, and the project features.

For the calculations presented in this paper, most of the assessment variables have been retrieved from the literature and relevant bibliography [32]. However, key assumptions are taken, providing the analysis hypothesis, based on the nature of the Station and the local characteristics, without reducing the value of the methodology, the modeling structure, and the application outputs.

4.1.1. Case Study Assumptions

The values we used to run this analysis are:

- The FSRU's average operation period is about 20 years; therefore, T = 20.
- The exchange rate (XR) of USD to Euro has been set to 0.8736 according to the 14 January 2022 exchange rate.
- The construction cost is set to 314,496,000 € [32].
- The owner's cost has been set to 10% of the construction cost, 31,449,600 € [32].
- The contingency ratio has been set to 15% of the construction cost, 47,174,400 € [32].
- Given the above and Equation (1), the ICC is estimated at 393,120,000 €.

- The level of ICC supports the assumption that it would not be fully funded by the shareholders' available cash, so we assume that half of the ICC will be funded by the shareholders, whereas the rest will be funded through borrowing. According to Equation (2), E = B = 196,560,000 €.
- This project can be financed by the Investment Bank, which are the commonly used instrument for such infrastructure projects. At the national level, this project would provide higher energy security in Greece by diversifying the ways of NG supply. At the local level, it can boost the local society economy by the direct employment it can offer (around 120 job places) and by creating a large circle of works that the FSRU needs. Thus, we assume that the Project will be financed by the EIB. The loan's interest rate is set to 3%, and the payment period to 20 years. As such, iRL = 3% and n = 20 years. Moreover, it is assumed that the payback of the loan shall start after the start of operation of the project.
- The annual loan installment is calculated via Equation (4) at 1,321,191,949 €.
- The total annual capacity of the vessel (Cv) will be 6.1 billion Nm^3, according to the Alexandroupolis FSRU [25].
- The second and binding market test for the reservation of capacity, conducted from the Alexandroupolis FSRU project initiative, bound 2.6 billion Nm3. This means that the usage rate (uf) can be set to at least 42% [25].
- The tariff of charge rate per Nm3 of NG we used in the analysis is the one that the Toscana FSRU Station uses for the year 2022 [34]. This is because the Toscana FSRU is geographically close to the Alexandroupolis FSRU, and Italy has the same currency as Greece (Euro). As such, we could assume that the tariff could be in the same range.
- The daily power and steam generation was estimated at 72,000 USD per day [32], which means that $PowCost_Y$ = 22,958,208 € per year.
- The rest-operating expenses are estimated at around 2.5% of construction costs. This value represents the OPEX for 100% of the Station's usage rate [32]. As such, $OPEX_{100\%}$ = 7,862,400 €.
- We assume that fixed costs and variable costs are in the same price range. As such, we can set ai = bi = 0.5, for i = 1 to T.
- We assume small annual capital costs at the range of 1% of ICC. As such, ci = 1%, for i = 1 to T.
- According to Greek tax legislation, the depreciation rate for industrial areas and storages is 4%. Due to the fact that we have used straight line depreciation, and the biggest part of the capital costs (initial and annually) refer to heavy equipment and assets, we assume that dcon = dcapexi = 4%, for i = 1 to T.
- After the end of the operation period of the Station, the FSRU's Vessel still has quite a high remaining value, as it can be modified and used in other applications (i.e., LNG carrier). Moreover, the subsea and onshore pipelines are made of steel, which has a high scrap value. For this reason, we assume that the salvage value can be set at 25% of the initial value both for the initial capital cost and the annual capital costs. As such, SALcon = SALCAPEXi = 25% of initial value, for i = 1 to T.
- The nature of the project includes mainly physical assets, instead of intangible assets. This is why we can assume that amortization costs are not applicable to this analysis, and Ai = 0, for i = 1 to T.
- The tax imposed to all companies in Greece for the year 2021 was 22%. In the analysis, we have used the same tax rate, so tax(i) = 22%, for i = 1 to T.

4.1.2. Case Study Results

Applying the above data and values, we get the economic results. The most important of them are presented in Table 1.

Table 1. Results of economic assessment.

Year	Depreciation (€)	EBT (€)	Taxes (€)	Net Earnings (€)	Cash Flow (€)
1	9,529,229	62,795,895	13,815,097	48,980,798	52,654,735
2	9,623,578	63,140,453	13,890,900	49,249,554	52,627,212
3	9,717,926	63,498,179	13,969,599	49,528,580	52,598,240
4	9,812,275	63,869,467	14,051,283	49,818,184	52,567,777
5	9,906,624	64,254,724	14,136,039	50,118,685	52,535,777
6	10,000,972	64,654,369	14,223,961	50,430,408	52,502,195
7	10,095,322	65,068,834	14,315,143	50,753,690	52,466,982
8	10,189,670	65,498,563	14,409,684	51,088,879	52,430,090
9	10,284,019	65,944,015	14,507,683	51,436,332	52,391,469
10	10,378,368	66,405,660	14,609,245	51,796,415	52,351,066
11	10,472,717	66,883,986	14,714,477	52,169,509	52,308,829
12	10,567,066	67,379,492	14,823,488	52,556,003	52,264,701
13	10,661,414	67,892,693	14,936,392	52,956,301	52,218,628
14	10,755,763	68,424,121	15,053,307	53,370,814	52,170,549
15	10,850,112	68,974,322	15,174,351	53,799,971	52,120,405
16	10,944,461	69,543,860	15,299,649	54,244,211	52,068,134
17	11,038,810	70,133,314	15,429,329	54,703,985	52,013,673
18	11,133,158	71,106,006	15,643,321	55,462,684	51,877,155
19	11,227,507	71,747,985	15,784,557	55,963,429	51,815,719
20	11,321,856	72,412,055	15,930,652	56,481,403	51,751,817

Continuing the analysis, we proceed with the calculation of the economic indicators of NPV and IRR, using the Equations (27) and (28). We set the discount rate at 4.9%, as was given for Greece from the European Commission for 1 January 2022, and we consider that the construction period will last for 2 years. Given the above, the NPV and IRR are calculated as follows:

- NPV = 214,463,908 €;
- IRR = 9.46%.

Figure 2 depicts the NPV for the Alexandroupolis FSRU.

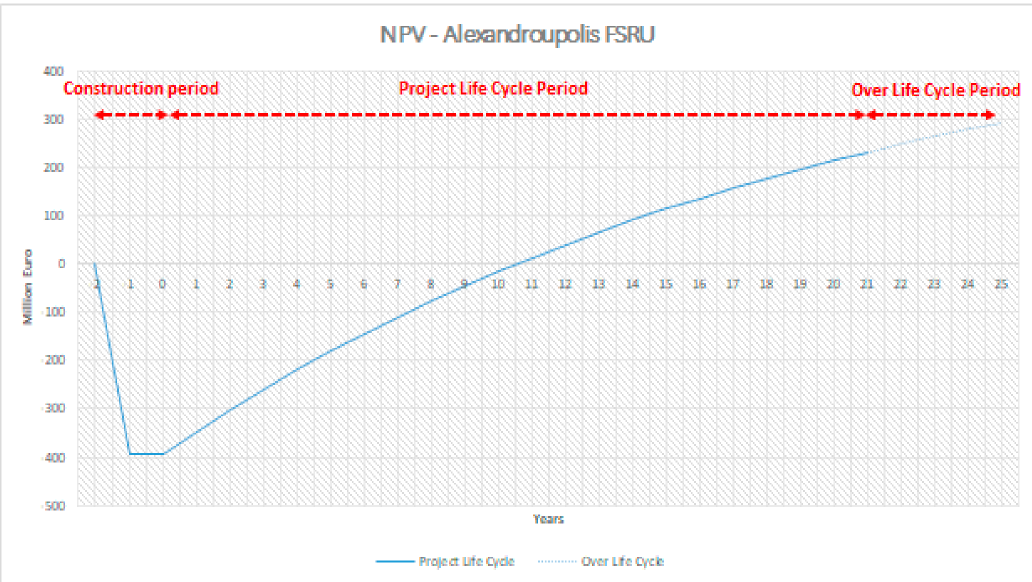


Figure 2. NPV for the Alexandroupolis FSRU Project.

Finally, with the help of Equations (15) and (17), the remaining value of the assets of the Station are calculated at 168,884,352 €.

Discussing the results of the analysis, we can ascertain that the economic output of the Project, given the assumptions we made, can definitely be positive and profitable. The net earnings, even after the taxes and expenses, can attribute to a very high profitability, which makes the project attractive enough to investors. The NE of the 1st year of operation reaches 12.46% of the ICC. This means that in only a few years, the ICC can be recuperated.

Evaluating the assessment using the economic indicators of NPV and IRR, the Project is also characterized as profitable and viable. The NPV at the end of operation period is not only positive, but has reached around 214 million €, which is 54.55% of the ICC. This means that, even estimating the discount rate of money for all 20 years of operation, the investment can give a high percentage of profit. As far as it concerns the IRR, it reaches 9.46%, which is 1.93 times higher than the discount rate of Greece (4.9%) at this time.

Last but not least, the remaining value of the assets at the end of the operation period, including both initial capital cost and capital costs during each year of operation, is still high enough, giving the investors the opportunity to gain high profits during the decommissioning period also.

4.2. Sensitivity Analysis

The above results were calculated using a relatively small usage rate of 42% of the FSRU. This means that there are bigger profit margins if this rate increases. On the other hand, if it drops even more, there is a doubt if the Project can remain economically viable or not. The same questions will be raised if other rather unstable parameters, such as USD/EUR exchange rate or tariff price, change. In this section, a sensitivity analysis is conducted to fully understand and highlight the dependence of the Project's profitability in relation to various parameters of the FSRU.

4.2.1. Usage Rate

Implementing infrastructure projects, the demand curves are essential and critical to assess feasibility and economic viability. Therefore, the sensitivity analysis should keep all the values stable, and change the demand of the Station, which is expressed by the usage rate. Applying a series of usage rates, the NPV, IRR, and net earnings using the methodology of Section 3 are calculated. The usage rate that was adopted during the presented (basic) scenario, based on values resulting from a market sounding survey conducted before the COVID-19 pandemic by the FSRU investors, constitute the most reliable scenario. Furthermore, higher demand scenarios, even it seems too optimistic for a greenfield energy infrastructure project, are considered in this numerical application, taken into account the new conditions in European energy market where new infrastructure for LNG supply is in major attention. However, the recent conflicts in North-East Europe where Russia is acting may provide a great opportunity for new business, and generate additional demand.

Initially, in the analysis, the hypothesis of a light volatility around the regular scenario's usage rate value was taken into consideration. Assuming that the volatility will be 20%, the values of usage rate to be examined are 33.6% for the high-risk scenario, and 50.4% for the positive market reaction scenario. Furthermore, the calculation assumed the hypothesis of a high increase for LNG demand that increases the demand 1.5 times higher than the regular scenario demand, forming the usage rate at 63%.

The results issued for each scenario are presented in Table 2.

Table 2. Results of demand-usage rate sensitivity analysis.

Scenario of Usage Rate	IRR	Change of IRR Compared to Regular Scenario	NPV (€)
Regular scenario—42%	9.26%	-	214,463,908
High Risk—33.6%	6.03%	−34.9%	47,946,786
Positive Market—50.4%	12.02%	29.8%	361,721,600
LNG High Demand Increase—63%	15.60%	68.4%	597,052,711

Moreover, Figure 3 presents the NPV during the operation period for each scenario.

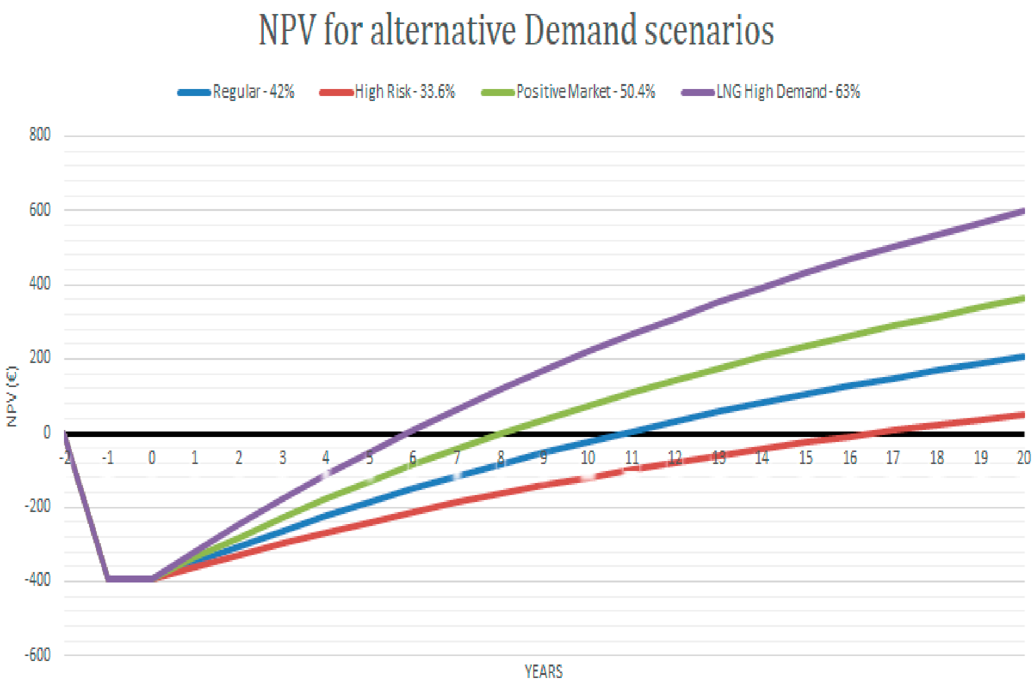


Figure 3. NPV during operation period for alternative usage rate scenarios. (NPV in millions Euro).

Assessing the above results, it can be highlighted that the project profitability is very sensitive to the demand curves (usage rate). A small increase in the demand annual volume from the level of 42% (regular scenario) to 50.4% can improve essential the IRR to a level above 12%, stimulating the investors' interest. Furthermore, in the LNG high-demand scenario, where the demand increases to a 63% usage rate, the IRR reached the level of 15.6%. On the contrary, in the high-risk scenario, where the demand reduces to 33.6%, the IRR can drop to levels close to the discount rate, leading the investment to be non-profitable enough. It is noteworthy that although the change in demand is the same (20%) in both the high-risk and positive market scenario, the variation of IRR is bigger when the demand decreases (34.9% to regular scenario), compared to when the demand increases (29.8% to regular scenario).

The same conclusions also apply for the NPV. In the LNG high-demand scenario, NPV turns positive after only 6 years, which in an operation period of 20 years, can lead to extremely high profitability. In the case of the high-risk scenario, where a small decrease occurs, NPV remains negative for a long period, until it turns positive near the end of operation period at around 17 years.

4.2.2. USD/EUR Exchange Rate

For the second part of the sensitivity analysis, the fluctuation of the USD to Euro Exchange Rate (XR) is taken into consideration in the analysis. This rate is affected by exogenous issues to the project e.g. accidents, political instability, etc.) and changes in energy market result higher price volatility on one hand; and higher construction and operational cost on the other.

The exchange rate values for this analysis tracked, by extrapolate, the historical data of XR from the commencement of the Euro circulation in 2000 until 2021, where:

- The highest rate recorded in 2001 (USD/EUR XR: 1.11);
- The lowest rate recorded in 2008 (USD/EUR XR: 0.68);
- The average rate during the 2000–2021 period (USD/EUR XR: 0.83).

As we can notice, the average rate (0.83) is close enough to the rate that we used during our regular scenario (0.87). The results for each scenario are presented in Table 3, and the NPV during the operation period is given in Figure 4.

Table 3. Results of USD/EUR exchange rate sensitivity analysis.

Scenario of USD/EUR Exchange Rate (XR)	IRR	Change of IRR Compared to Regular Scenario	NPV (€)
Regular scenario—0.87	9.46%	-	214,463,908
High XR—1.11	5.51%	−40.55%	32,147,103
Low XR—0.68	13.70%	47.90%	362,865,064
Average XR—0.83	10.31%	11.36%	248,027,423

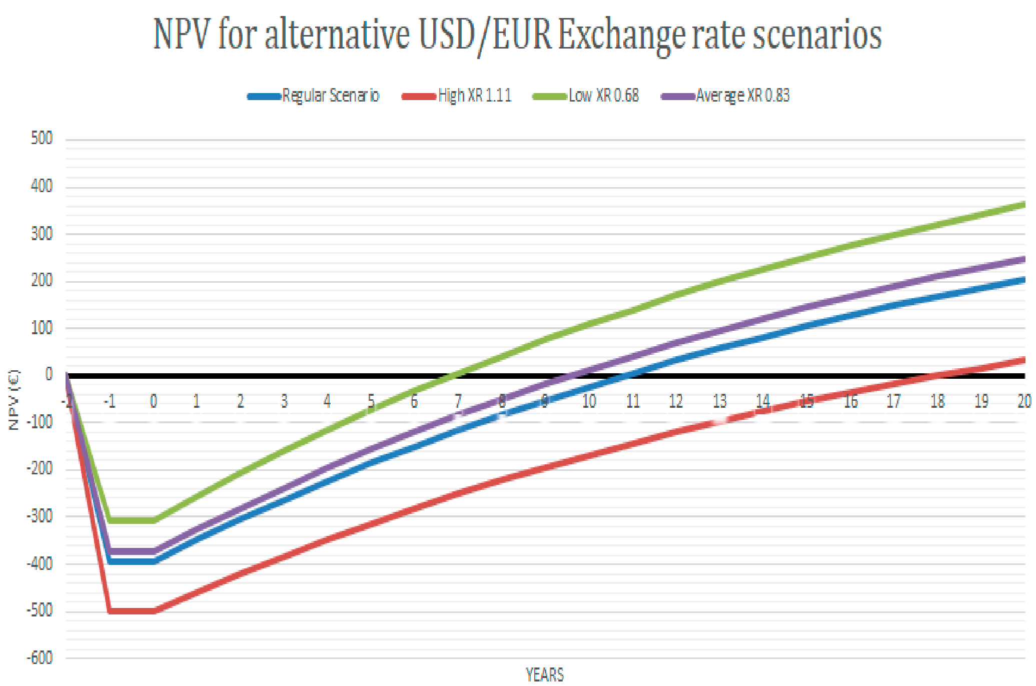


Figure 4. NPV during operation period for alternative USD/EUR exchange rate scenarios. (NPV in million Euro).

Appreciating the above data, we can comprehend that the Project's economic rates are volatile enough to the XR's changes. Both IRR and NPV fluctuate in large ranges that could threaten the Project's viability. The IRR ranges between 5.51% and 13.70%, whereas the NPV ranges from 32 mil € to over 362 mil €. Especially in the high XR scenario, the NPV remains negative for almost all of the operation period of the Project.

4.2.3. Tariff Price—Sensitivity Analysis

Finally, a tariff price sensitivity analysis is conducted. The tariff is a parameter that, although it is determined by the FSRU, also takes into consideration exogenous factors, such as the competition, the demand, etc. In this analysis we try to set the boundaries where the tariff price may range, and where the Project will still be economically viable. This is why we have chosen decreased values compared to the regular scenario. The used tariff price's values are for a 10% decrease, 20% decrease, and 30% decrease.

The results for each scenario are given in Table 4, whereas the NPV during the operation period is depicted in Figure 5.

Table 4. Results of tariff price sensitivity analysis.

Scenario of Tariff Price	IRR	Change of IRR Compared to Regular Scenario	NPV (€)
Regular scenario	9.46%	-	214,463,908
Decrease 10%	7.72%	−16.66%	125,598,776
Decrease 20%	5.79%	−37.48%	37,453,644
Decrease 30%	3.58%	−61.33%	−5,105,148,745

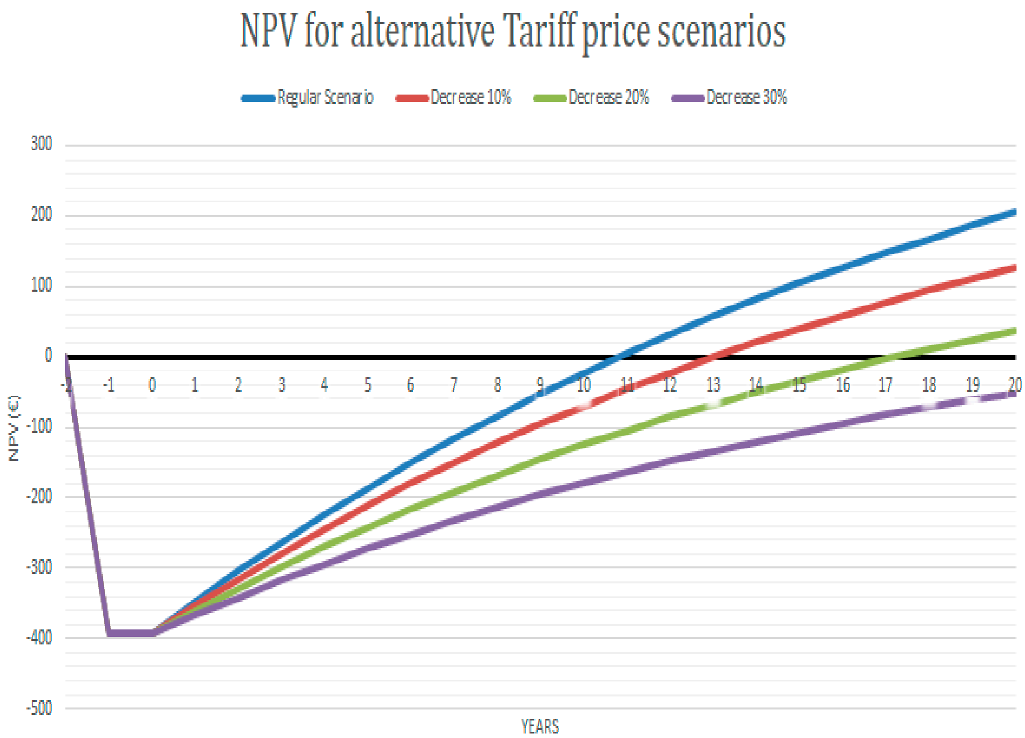


Figure 5. NPV during operation period for alternative tariff price scenarios.

As we see from the analysis's results, in the first scenario, although the decrease is in the range of 10%, the Project can still produce satisfied earnings with 7.72% IRR. When the decrease goes to 20%, the NPV remains marginally positive, but with an extremely small amount of earnings. On the contrary, when the tariff's decrease reaches 30%, the Project turns undoubtedly unviable.

The analysis proves that the FSRU may decrease its tariff price until around 10% and still maintain satisfactory earnings. If the external circumstances require a bigger decrease, then the Project will either lose much more of its economic efficiency or will be economically unviable.

The extremely high sensitivity of the investment to all the checked parameters indicates that before the final investment decision is taken, the shareholders group must acquire not only all the necessary data that concern the FSRU, but also be sure that the external factors, such as the USD/EUR exchange rate, are in favor of the Project.

4.3. Project Incentives

Based on the formulation of Section 3.9, the extra tax income the state could gain from the FSRU Project is estimated by using Equation (30) under the following data and assumptions:

- The construction cost has been set at 314,496,000 €, as mentioned above in Section 4.1.
- The tax rate during the construction can be set at 22%, which was the tax rate for companies in Greece for 2021.
- The FSRU employs around 120 people. If we consider that the average wage will be 1500 € per month, which is an average technical wage for Greece, then the total yearly salaries of FSRU shall be 2,520,000 €. In this amount, we have also included two extra wages for the Christmas and summer periods.
- The tax rate for the wage of 1500 € in Greece is around 25%. Assuming also that the employees will spend 2/3 of their income on purchases and services, they will generate extra turnover which is taxed by 24%. This way, they produce extra taxes in the amount of 12% of their wage. Therefore, the employees generate a total of 37% taxes out of their wage.
- Using the data of Section 4.1, the total turnover generated by the annual operating and capital costs of the FSRU during the operating year i, expressed by Equation (29), is estimated at 6,207,264 €. The tax rate for these expenses is set at 22%, which was the tax rate for companies in Greece for 2021.
- The usage rate of 42% means that during each operating year, 150 LNG carriers will visit the FSRU. The income that the FSRU will generate for the local community from the above number of carriers, and the other visitors that will visit Alexandroupolis (i.e., technical expertise from abroad), can be set at around 250,000 €. The tax rate for this is set at 24% according to Greek legislation for the taxation of goods.

Applying these data to Equation (30), the total state income from these activities is 116,349,082 €, as shown in Table 5.

Table 5. Taxes generated by FSRU Project over years.

Activity	Expenses Generated during Construction Period (€)	Expenses Generated during Each Operation Year (€)	Tax Rate Imposed	Tax Gained during Construction Period (€)	Tax Gained during Operation Period of 20 Years (€)
Construction period costs	314,496,000	-	22%	69,189,120	-
Employees' wages	-	2,520,000	37%	-	18,648,000
Operation and capital expenditures	-	6,207,264	22%	-	27,311,962
Other activities	-	250,000	24%	-	1,200,000
			Total income during FSRU Project	116,349,082	

The state should carefully consider how to use this amount. The state may decide to give the entire amount back to the FSRU, or a big or a small part of it. It may decide to give it back all at once during the first years of operation, or give it back gradually with a small amount every year. Furthermore, the state, knowing that they will gain extra income, may decide to finance the Project, or to become a shareholder by acquiring a percentage of the investment.

In the analysis, the project implementation incentives by the state in terms of tax relief over the years, are examined. This way, if the operating period is 20 years, the state may offer a tax relief of 5,817,454 € for each operating year, and the taxes that the FSRU must pay are given by Equation (31). Using these taxes, the NPV and IRR are recalculated using the equations of Section 3.8, and the adjusted results reach the values of 280,909,698 € for NPV and 10.67% for IRR. Compared to the results of the regular scenario, the increase is 30.98% for NPV and 12.79% for IRR, respectively.

5. Discussion

When it comes to investing in an energy project, the decision is not easy, and other than the technical restrictions and environmental considerations, a series of business and economic risks need to be taken into consideration. In real-life applications, a group of alternative scenarios needs to be appropriately developed to evaluate project risk, and promote measures to mitigate them. In this frame, the paper structure and the application results presented to support decisions and assess risks over the project lifecycle have taken into consideration changes driven by operational and external events. Based on the proposed analysis developed in this paper, the framework for developing alternative scenarios is given towards decisions on equity funding schemes and the added value on assets over time.

To mitigate the investment risk and to increase the financing leverage, an introduction of governmental or authorities' incentives are discussed. Taking into consideration the investment condition of the FSRU Alexandroupolis case study, a tax substitute incentive measure was discussed as a risk-sharing tool to boost the project implementation. The numerical application results could be essential drivers for decisions in similar cases, and illustrate comparisons with other case studies.

Finally, considering the geopolitical conditions and the new LNG energy strategy discussed in Europe, and the implementation of flexible offshore LNG terminal facilities in the European territory, it shall be extremely interesting to evaluate their economic performance, providing results on the viability and investment attractiveness of such projects in the European continent. The existence of real data also assists us to get an accurate economic result. Moreover, this framework application shall be useful to the research community, getting it compared to similar projects from all over the globe.

6. Conclusions

This paper deals with the feasibility appraisal framework from an economic point of view, dedicated to FSRU greenfield (new) energy projects. The decisions for such projects vary from a very short period up to many decades, due to the complexities driven by the stakeholders' expectations, the long-term payback period, the availability of capital, and the energy demand volatility raising business risks. The appraisal modelling structure provides an easy-to-handle tool to support energy project initiatives and prioritize energy investment decisions.

The modelling structure set a dynamic project appraisal modeling framework for the economic assessment of the FSRU projects that could support the involved parties to initiate project implementation. The proposed modelling structure is recommended to be used even for evaluating the project feasibility in the planning (initiative) stage even as a tool for monitoring project performance over time. The methodology section set an analytical, coherent, detailed, easy-to-use modeling framework dedicated for new FSRU projects. By breakdown, the project implementation, delivery, and operational characteristics of all the variables dealing with the project economic performance are taken into consideration. The modelling structure is depicted appropriately for planners and managers to support analysis in both: (a) to assess the investment, and comprehend and evaluate how each variable contributes to the project economic performance over time; and (b) to strategically appraise the future course of the project or to re-assess the performance into changed energy market (demand) or financial (investment) conditions.

Furthermore, the results of a sensitivity analysis are analyzed to discuss the level of dependency of FSRU projects to the demand and financing parameters, providing key messages regarding the FSRU projects risks, viability, and attractiveness. It is noteworthy that in terms of business risk mitigation, some key incentives are evaluated and highlighted, illustrating a risk-sharing mechanism that may increase the investment attractiveness, or share risk and benefits between involved parties.

The numerical case study is the Alexandroupolis FSRU Project, and we have pointed out the conditions and the frame in which this investment can become viable and profitable, considering the Project's internal and external conditions representing the appraisal modelling variables. The numerical application evaluates the project performance for a basic scenario, promoting key messages to decision makers regarding the project risks and estimations uncertainty. The sensitivity analysis evaluating the project outputs over time for different demand scenarios and project financing features (equity mix, currency and exchange volatility) highlighting key messages for similar projects. Nevertheless, the case study outputs could provide an essential background for comparisons in similar projects, and illustrate key messages to decision-makers for the feasibility of such a project due to energy market turbulences affecting Europe and other regions. The growing opportunities, and the investment attractiveness for implementing new LNG projects due to the North-East Europe conflicts, is an interesting issue, which is highly recommended for further investigation. The governmental incentives and the conditions to be affected to mitigate the investment risks should also be an interesting issue for dedicated research analysis.

This research received no external funding.

Author Contributions: Conceptualization, D.D.; methodology, D.D. and P.Z.; software, P.Z.; validation, D.D. and P.Z.; formal analysis, D.D.; investigation, P.Z.; resources, D.D.; data curation, P.Z.; writing—original draft preparation, P.Z.; writing—review and editing, D.D.; visualization, P.Z.; supervision, D.D.; project administration, D.D.; funding acquisition, D.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: The paper uses a conceptual analysis framework, case study inputs, and analysis outputs developed in the research project "ENIRISST–Intelligent Research Infrastructure for Shipping, Supply Chain, Transport and Logistics", implemented in the Action "Reinforcement of the Research and Innovation Infrastructure", funded by the Operational Programme "Competitiveness, Entrepreneurship and Innovation" (NSRF 2014–2020), and co-financed by Greece and the European Regional Development Fund.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Dester, M.; Andrade, M.; Bajay, S. New Renewable Energy Sources for Electric Power Generation in Brazil. *Energy Sources Part B Econ. Plan. Policy* **2012**, *7*, 390–397. [CrossRef]
2. Severová, L.; Svoboda, R.; Kopecká, L. Increase in prices of farmland in the Czech Republic. *Prop. Manag.* **2017**, *35*, 326–338. [CrossRef]
3. Rompokos, P.; Kissoon, S.; Roumeliotis, I.; Nalianda, D.; Nikolaidis, T.; Rolt, A. Liquefied Natural Gas for Civil Aviation. *Energies* **2020**, *13*, 5925. [CrossRef]
4. European Commission. Directorate-General for Energy. In *EU Energy in Figures: Statistical Pocketbook 2021*; Publications Office: Luxembourg, 2021.
5. ENTSOG-Transparency Platform (TP). Transparency Platform-Points Map. 2021. Available online: https://transparency.entsog.eu/#/map?loadBalancingZones=false (accessed on 18 January 2022).
6. Božić, F.; Karasalihović Sedlar, D.; Smajla, I.; Ivančić, I. Analysis of Changes in Natural Gas Physical Flows for Europe via Ukraine in 2020. *Energies* **2021**, *14*, 5175. [CrossRef]

7. Mitrova, T.; Boersma, T.; Galkina, A. Some future scenarios of Russian natural gas in Europe. *Energy Strategy Rev.* **2016**, *11–12*, 19–28. [CrossRef]
8. Lee, Y. Interdependence, issue importance, and the 2009 Russia-Ukraine gas conflict. *Energy Policy* **2017**, *102*, 199–209. [CrossRef]
9. Energy Policy: General Principles. Available online: https://www.europarl.europa.eu/factsheets/en/sheet/68/energy-policy-general-principles (accessed on 18 January 2022).
10. Sun, H.; Zhu, H.; Liu, F.; Ding, H. Simulation and optimization of a novel Rankine power cycle for recovering cold energy from liquefied natural gas using a mixed working fluid. *Energy* **2014**, *70*, 317–324. [CrossRef]
11. Majid, M.A.A.; Ya, H.H.; Mamat, O.; Mahadzir, S. Techno Economic Evaluation of Cold Energy from Malaysian Liquefied Natural Gas Regasification Terminals. *Energies* **2019**, *12*, 4475. [CrossRef]
12. Tjahjono, T.; Ehyaei, M.A.; Ahmadi, A.; Hoseinzadeh, S.; Memon, S. Thermo-Economic Analysis on Integrated CO_2, Organic Rankine Cycles, and NaClO Plant Using Liquefied Natural Gas. *Energies* **2021**, *14*, 2849. [CrossRef]
13. Lv, Q.; Liu, H.; Wang, J.; Liu, H.; Shang, Y. Multiscale analysis on spatiotemporal dynamics of energy consumption CO_2 emissions in China: Utilizing the integrated of DMSP-OLS and NPP-VIIRS nighttime light datasets. *Sci. Total Environ.* **2020**, *703*, 134394. [CrossRef]
14. Gómez, M.R.; Garcia, R.F.; Gómez, J.R.; Carril, J.C. Thermodynamic analysis of a Brayton cycle and Rankine cycle arranged in series exploiting the cold exergy of LNG (liquefied natural gas). *Energy* **2014**, *66*, 927–937. [CrossRef]
15. D'alessandro, A.A.; Izurieta, E.M.; Tonelli, S.M. Decision-making tool for a LNG regasification plant siting. *J. Loss Prev. Process Ind.* **2016**, *43*, 255–262. [CrossRef]
16. Papaleonidas, C.; Androulakis, E.; Lyridis, D.V. A Simulation-Based Planning Tool for Floating Storage and Regasification Units. *Logistics* **2020**, *4*, 31. [CrossRef]
17. Kulitsa, M.; Wood, D. Floating storage and regasification units face specific LNG rollover challenges: Consideration of saturated vapor pressure provides insight and mitigation options. *Nat. Gas Ind. B* **2018**, *5*, 391–414. [CrossRef]
18. Martins, M.R.; Pestana, M.A.; Souza, G.F.M.; Schleder, A.M. Quantitative risk analysis of loading and offloading liquefied natural gas (LNG) on a floating storage and regasification unit (FSRU). *J. Loss Prev. Process Ind.* **2016**, *43*, 629–653. [CrossRef]
19. Austvik, O.G.; Rzayeva, G. Turkey in the geopolitics of energy. *Energy Policy* **2017**, *107*, 539–547. [CrossRef]
20. IGU. *2020 World LNG Report—IGU*; IGU: Barcelona, Spain, 2020; p. 68. Available online: https://www.igu.org/resources/2020-world-lng-report/ (accessed on 18 January 2022).
21. IGU. *2021 World LNG Report—IGU*; IGU: Barcelona, Spain, 2021; pp. 134–139. Available online: https://naturgas.com.co/wp-content/uploads/2021/07/IGU_WorldLNG_2021_compressed.pdf/ (accessed on 18 January 2022).
22. King & Spalding LLP. *LNG in Europe 2018—An Overview of LNG Import Terminals in Europe*; King & Spalding LLP: Atlanta, GA, USA, 2018; p. 7. Available online: https://www.kslaw.com/attachments/000/006/010/original/LNG_in_Europe_2018_-_An_Overview_of_LNG_Import_Terminals_in_Europe.pdf?1530031152 (accessed on 18 January 2022).
23. Hellenic Gas Transmission System Operator (Desfa). *Development Study 2021–2030*; Desfa: Athens, Greece, 2020.
24. Desfa Yearly NNGS Allocation Data 2020. Available online: https://www.desfa.gr/userfiles/pdflist/DERY/TT/Et.Stoix.ESFA_2020.pdf (accessed on 18 January 2022).
25. Gastrade. Available online: http://www.gastrade.gr/en/the-company/the-project.aspx (accessed on 18 January 2022).
26. Dimitriou, J.D. Quantitative evaluation taxonomy for transport infrastructure projects. *Int. J. Res. Sci. Manag.* **2017**, *4*, 34–40. [CrossRef]
27. Dimitriou, J.D. Deterministic Modeling to Estimate Economic Impact from Implementation and Management of Large Infrastructure. *Int. J. Ind. Syst. Eng.* **2017**, *11*, 2754–2759. [CrossRef]
28. Dimitriou, J.D.; Sartzetaki, F.M. Assessment of socioeconomic impact diversification from transport infrastructure projects: The case of a new regional airport. *Transp. Res. Rec.* **2022**, *2676*, 03611981211064999. [CrossRef]
29. Dimitriou, J.D.; Sartzetaki, F.M.; Dadinidou, S. Methodology Framework to Assess Regional Development Plans: A European Perspective Approach. *J. Econ. Bus.* **2022**, *5*, 1–12. [CrossRef]
30. Dimitriou, J.D.; Mourmouris, C.J.; Sartzetaki, F.M. Economic impact assessment of mega infrastructure pipeline projects. *Appl. Econ.* **2015**, *47*, 4310–4322. [CrossRef]
31. Dimitriou, J.D.; Sartzetaki, F.M. Assessment framework to develop and manage regional intermodal transport network. *Int. J. Res. Transp. Bus. Manag.* **2020**, *35*, 100455. [CrossRef]
32. Songhurst, B. *The Outlook for Floating Storage and Regasification Units (FSRUs)*; The Oxford Institute for Energy Studies: Oxford, UK, 2017; pp. 16–32.
33. Songhurst, B. *Floating LNG Update-Liquefaction and Import Terminals*; Oxford Institute for Energy Studies: Oxford, UK, 2019.
34. OLT Offshore LNG Toscana. Available online: https://www.oltoffshore.it/en/business-area/gas-year-2021-2022-2/tariffs/ (accessed on 18 January 2022).

energies

Review

Oil Prices and the Hydrocarbon Markets: A Review

Ali Jadidzadeh [1,2,†], Mobin Mirzababaei [1,†] and Apostolos Serletis [3,*,†]

[1] Department of Economics, University of Tehran, Tehran 1411734115, Iran
[2] The School of Public Policy, University of Calgary, Calgary, AB T2P 1H9, Canada
[3] Department of Economics, University of Calgary, Calgary, AB T2N 1N4, Canada
* Correspondence: serletis@ucalgary.ca; Tel.: +1-(403)-220-4092; Fax: +1-(403)-282-5262
† These authors contributed equally to this work.

Abstract: In this paper, we review the literature that investigates the impact of oil price shocks on the selected hydrocarbon prices. First, we present the empirical studies that presume, due to the global nature of the crude oil market, that the world oil price is an exogenous determining variable to the evolution of the local hydrocarbon markets such as natural gas or natural gas liquids (NGLs). Then, we present recent empirical studies that have improved our understanding of the source of oil price changes. They treat the real price of oil as an endogenous variable, identify the causes underlying oil price shocks, and then evaluate the impact of structural supply and demand shocks on the other hydrocarbon prices. The first strand of studies does not represent a consensus on the relationship between crude oil and other hydrocarbon prices—some demonstrate stable and asymmetric relationships, and some find no relationship or a very weak relationship. The second strand of studies shows that oil supply-side shocks have a transitory and temporary impact while oil demand-side shocks have a persistent and permanent impact on other hydrocarbon prices. In addition, it shows that the structural shocks in the global crude oil market explain approximately 50% of the variation in the other hydrocarbon markets in the long run.

Keywords: oil price shocks; hydrocarbon markets; transmission channels; asymmetries

Citation: Jadidzadeh, A.; Mirzababaei, M.; Serletis, A. Oil Prices and the Hydrocarbon Markets: A Review. *Energies* **2022**, *15*, 6192. https://doi.org/10.3390/en15176192

Academic Editors: Bernard Ziębicki and Edyta Bielińska-Dusza

Received: 12 July 2022
Accepted: 22 August 2022
Published: 25 August 2022

1. Introduction

Since the second oil shock of 1979–1981 and the consequent increased oil price volatility, energy market stakeholders and researchers have paid more attention to how energy commodity prices are linked to oil price fluctuations. In the last two decades, the expansion of unconventional oil from shale and tar sands has also challenged many underlying beliefs that oil prices are the main driver of other hydrocarbon prices. For example, the crude oil and natural gas prices in the United States were moving together, but they have started to decouple episodically since 2000—see Jadidzadeh and Serletis [1] for more detail. Since then, the improvements in both theoretical and empirical studies modeling the sources of oil price shocks have evolved our understanding of the interaction between integrated *global* oil markets and *local* hydrocarbon markets.

Understanding the behavior of price volatility in hydrocarbon markets is significant for several reasons. Persistent changes in volatility can affect the risk exposure of energy producers and investors and alter their incentives to invest in natural gas and oil sectors and facilities for production and transportation. Likewise, volatility is a key determinant of the value of commodity-based contingent claims, whether financial or real. In addition, based on the recent trends toward increasing global trade in petroleum products, Zavaleta et al. [2] discuss that mainly due to a significant increase in global refining capacity utilization the global petroleum refining industry is moving from a primarily local to a global market structure. Thus, reviewing the studies that investigate the determinants of volatilities in hydrocarbon markets is important for derivative valuation, hedging decisions, decisions to invest in physical capital concerning the production or consumption of hydrocarbons, and undertaking plausible policy decisions on key energy commodities by policy makers [3].

Therefore, this article aims to present a selective review of the studies on the effect of oil price shocks on selected hydrocarbon prices, primarily natural gas and natural gas liquids (namely, ethane, propane, normal butane, iso-butane, and natural gasoline). As most literature on the effect of oil price shocks on hydrocarbon prices has employed U.S. data that provide long historical time-series data to test and run econometric models, we focus mainly on the U.S. hydrocarbon markets. We first discuss the channels through which crude oil price shocks impact hydrocarbon prices and then present the empirical econometric methods that explore the relationship between oil price shocks and the hydrocarbon prices based on the economic theories.

The economic theories that explain the relationship between oil and hydrocarbon prices consider either substitutability between oil and hydrocarbons (a demand-side linkage) or the way that hydrocarbons are extracted from oil and gas (a supply-side linkage). With regard to the relationship between oil and natural gas liquids (NGLs), it should be noted that crude oil is not consumed directly, but it is the main source of hydrocarbons, such as methane, ethane, propane, butane, pentane, and various other paraffinic, naphthenic, and aromatic hydrocarbons which are derived from refining crude oil. Similarly, the raw natural gas extracted from gas wells is refined to produce the end products including methane and natural gas liquids (NGLs). Methane, delivered by pipelines, is the main source of heating and burning in the residential, commercial, and industrial sectors, and NGLs, stored and shipped in a liquid state, are used as feedstocks in petrochemical plants, space heating, motor gasoline components, and other fuel use. Therefore, it is the demand for refinery and petrochemical end-products that drives the demand for crude oil and natural gas. Therefore, the shocks in oil and gas markets lead to changes in the production costs and, consequently, the price of NGLs. In addition, Oglend et al. [4] argue that the oil and natural gas markets are also related through the state of the NGLs markets. The liquids' prices are determined in a market that is indexed to oil prices with long-term contracts. Therefore, an increase in oil prices might raise NGL prices.This might make natural gas producers increase their production, as NGLs are a key source of income for them, consequently lowering natural gas prices.

About the relationship between the crude oil market and the natural gas market, on the demand side, oil and gas compete indirectly with their derivatives. Methane (a natural gas derivative) and heating oil (a crude oil derivative) compete in the heating markets of residential and commercial sectors. Methane is also a substitute for the residual and distillate fuels in electricity generation and industrial plants. For example, Hartley et al. [5] argue that the installation of advanced combined cycle gas turbine (CCGT) power plants has increased the demand for natural gas relative to residual fuel oil in the United States. On the supply side, associated natural gas is a coproduct of crude oil as it occurs in oil reservoirs, whereas the non-associated natural gas is not in contact with crude oil and is found in natural gas reservoirs. Although associated natural gas accounts for a small fraction of natural gas production in the United States, it is also utilized to extract NGLs in oil refineries. In addition, recent technological innovations in horizontal drilling and hydraulic fracturing have increased the production of both shale oil and shale gas.

There are a large number of empirical studies that sought to investigate whether the price of crude oil was an important determinant of the natural gas price. However, less attention has been paid in the literature to the relationship between other hydrocarbon products and the oil market. Most of this literature employs time series models and can be categorized into two strands. The first strand of studies investigates the existence of correlation and long-run cointegrating relationships between oil and hydrocarbon prices using different types of time series models such as Vector Error Correction Models or Vector AutoRegressive (VAR) models. These studies mostly treat the price of oil as exogenous and investigate the response of other hydrocarbon prices to exogenous changes in the oil price. Basically, this literature shows that the relationship between the oil price and the natural gas or NGL prices is asymmetric in a way that the oil price predominantly drives the other hydrocarbon prices, but not the other way around. The second strand of studies treats the price of crude oil as endogenous and disentangles the causes underlying oil price shocks. This recent empirical literature, which is built on Kilian [6] employs a structural VAR model to identify the source of oil price fluctuations as a result of supply disruptions and demand changes in the integrated global oil market. They augment Kilian's structural VAR model to include the real price of another hydrocarbon and investigate the response of other hydrocarbon prices to the structural shocks in the oil market.

The paper is organized as follows. Section 2 discusses the channels through which oil price technically impacts other hydrocarbon prices. Section 3 reviews the literature that investigates the relationship between crude oil and other hydrocarbon markets, and the final section concludes the paper.

2. Transmission Channels between Oil and Hydrocarbon Prices

As illustrated in Figure 1, raw natural gas is extracted either from gas reservoirs or oil reservoirs. The former is called non-associated natural gas or wet gas, and the latter is called associated-dissolved natural gas. The associated natural gas is delivered to oil refineries to extract hydrocarbon gas liquids (HGLs). The HGLs from oil refineries are usually converted to olefins such as ethylene, propylene, normal butylene, and isobutylene to make resins, plastics, and adhesives in petrochemical plants. However, the non-associated gas is delivered to a gas processing plant and then to other facilities, namely, fractionators, to separate the majority of the hydrocarbon gas liquids (HGL) from the gas stream and to apply additional separation to meet certain commercial specifications. The end-products are natural gas liquids (NGLs), including ethane propane, normal butane, isobutane, and natural gasoline, which are abbreviated as C2, C3, NC4, IC4, and C5, respectively. The liquidation of NGLs makes possible their storage and delivery from remote producing areas, with oil-indexed prices and long-term contracts, to large consuming areas—see Jadidzadeh and Serletis [7], Wamsley [8], and the HGLs page by the U.S. Energy Information Administration [9] for more detail.

Crude oil is traded in a global marketplace where many international buyers and sellers are absent in a geographically proximate situation. However, markets for natural gas and refined petroleum products are typically considered national or even regional. Specifically, there are three major regional markets, including the North American, European, and East Asian trading hubs, where the prices of NGLs are determined. Three channels link NGL prices to oil prices. First, NGLs are either the direct product of crude oil or are used as blendstocks in petroleum products. For example, although a considerable share of NGLs is extracted from natural gas at the fractionators, a large amount originates from the crude oil at the refineries. Since 2000, the amount of U.S. HGLs production from petroleum refineries has remained almost unchanged at about 0.55 million barrels per day, while the production from natural gas processing plants has increased from 2.16 to 5.72 million barrels per day in 2020. Gasoline, which is the main product of crude oil, needs to be mixed with natural gasoline and normal butane to enhance combustion. So, the channel that the crude oil prices impact natural gasoline and normal butane through is the interplay of gasoline supply and demand. Second, the market structure of NGLs links the NGL contracts to oil prices. There are many trading gas hubs all over the world where NGL prices are determined by oil-indexation mechanisms that tie NGL prices to oil prices, compared to the gas-on-gas completion mechanism, where NGL prices are determined based on their supply and demand interactions [10]. Third, crude oil products such as heating oil compete with methane, propane, and butane through their utilization for fuel and heating. Furthermore, the development of the Liquefied Petroleum Gas (LPG) markets has strengthened the connection between the oil and gas markets. So, any change in oil or gas prices is expected to change the NGL prices either directly or indirectly.

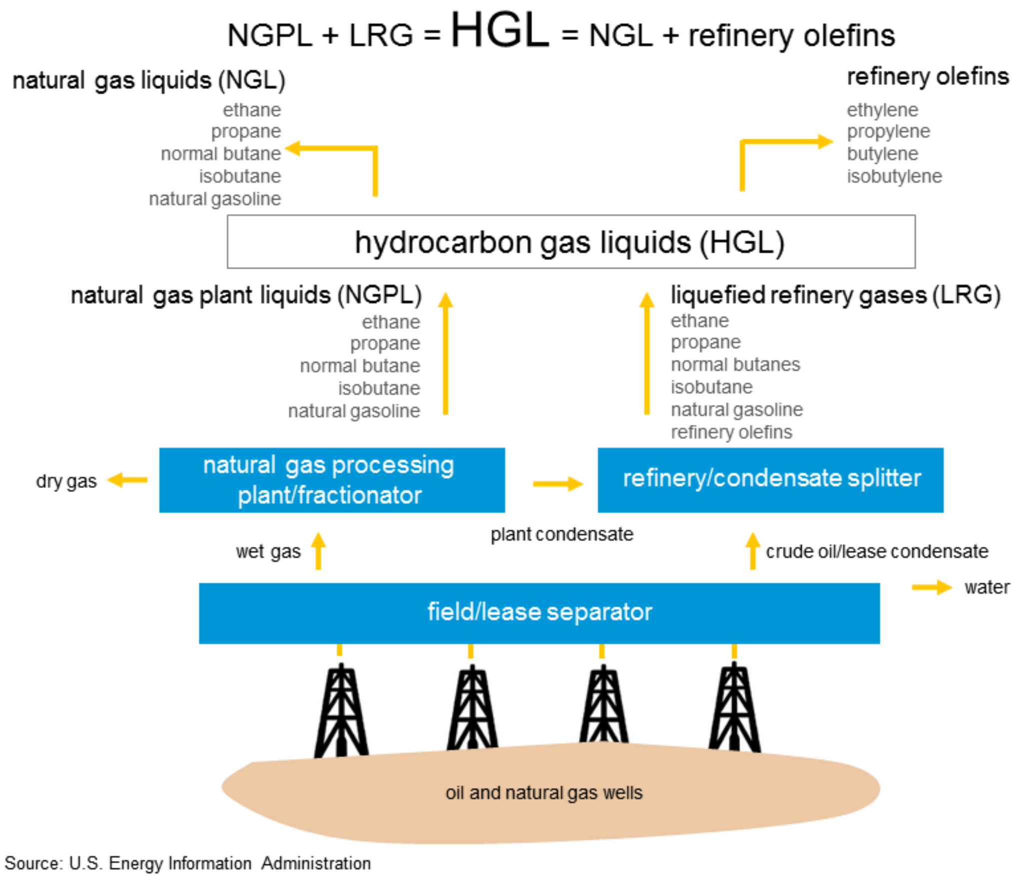


Figure 1. Sources of hydrocarbon gas liquids (HGL) and Natural gas liquids (NGL).

3. Empirical Models

In this section, we first review the studies that presume that the real price of oil is exogenous with respect to economic fundamentals, and supply disruptions, such as political events in the Middle East, only drive the oil price shocks. The key insight in them is that the relationship between oil price and other hydrocarbons is evaluated on a *ceteris paribus* basis—i.e., the oil price varies while all other variables are held constant. Then, we present recent empirical studies that are mostly built on Kilian [6] and treat the real price of oil as an endogenous variable. They believe that oil price fluctuations do not occur *ceteris paribus*. As a result, the volatility in the integrated global oil market is driven by both supply and demand shocks. They disentangle the source of price changes and then evaluate the impact of supply and demand shocks on the other hydrocarbon prices.

3.1. Oil Price as an Exogenous Variable

This line of study relies on the global nature of the crude oil market and presumes that large variations in the price of oil are historically driven by supply disruption as a result of political events and OPEC decisions. It assumes that oil prices are exogenous to macroeconomics variables and discards the source of oil price shocks in their analyses. Among those, some studies, such as Wang et al. [11], Brown and Yücel [12], Panagiotidis and Rutledge [13], Pindyck [3], Serletis and Rangel-Ruiz [14], and Serletis and Herbert [15], show that there is a stable and asymmetric relationship between the crude oil price and natural gas price in a way that the oil price dominantly derives the natural gas price, but not the other way around. On the contrary, other studies such as Bachmeier and Griffin [16], Drachal [17], and Zhang and Ji [18] show that, in the long run, there is no relationship or a very weak relationship between the prices of crude oil and natural gas. Serletis and Rangel-Ruiz [14] show that there are no shared stochastic trends between West Texas Intermediate (WTI) crude oil prices and Henry Hub natural gas. They attribute this to the deregulations of the natural gas market in the United States. Hailemariam and Smyth [19] argue that since the shale gas revolution in 2008 the price of natural gas has been determined based on its supply and demand in the natural gas market. In the short run, studies such as Hartley et al. [5] and Brown and Yücel [12] show that seasonal factors, such as weather and natural disasters, and oil inventories have a significant impact on natural gas prices, which makes them deviate from oil prices.

Yücel and Guo [20] is one of the first studies that investigated a cointegrating relationship between oil, natural gas, and coal prices from 1947 to 1990 in the U.S. They show that oil and natural gas are not cointegrated when using the full sample because the natural gas market was heavily regulated before 1974. However, their results verify that the cointegration exists episodically in sub-samples. For example, one can find a long-run relationship between oil and natural gas prices for the 1974–1990 time span in a way that the oil price drives natural gas prices—see also Hou and Nguyen [21], Hailemariam and Smyth [19], and Aruga [22], who verify Yücel and Guo's results over the 1974–1990 period. Similarly, Bachmeier and Griffin [16]'s study does not support the idea of a primary energy market as they show that oil, natural gas, and coal are very weakly integrated in the U.S. They argue that the end products of oil and natural gas are used in different sectors, while in the short-run, little possibilities of interfuel substitution exist. For example, oil and natural gas products, mostly heating oil and methane, can compete in residential and commercial heating or in power plants, while gasoline, which is mostly produced from oil, does not have a considerable successor to natural gas in the transportation sector. In contrast, Barcella [23] argues that fuel oil and natural gas are significant substitutes in the electric power sector and that is why crude oil and natural gas prices are highly correlated in the liberalized U.S. gas market. Therefore, the state of the transmission channels, discussed in the previous sections, is used to explain how the hydrocarbon prices are integrated with the crude oil prices. They attribute either changes in the state of market structure and regulations (i.e., oil-indexed versus gas-on-gas contracts), supply-side interruptions and developments, or demand-side changes in oil and gas derivatives to co-movements in the prices.

The liberalization of natural gas markets refers to the deregulation and structural reforms that lead to the gas-on-gas competition in liquid spot and futures markets rather than long-term contracts with prices determined in advance and frequently linked to the crude oil or heavy fuel price (a system known as oil-indexation). Some studies such as Barton and Vermeire [24] and Heren [25] believe that the liberalization of gas markets in the U.K. has weakened the linkage between crude oil and gas prices since the spot and futures markets were first established in 1995–1996. Asche et al. [26] employ cointegration models and show that the U.K. natural gas market and Brent oil are integrated in an interim period (1995–1998) when the U.K. gas market was liberalized in 1995 but not yet linked to the Continental gas markets through the U.K.–Mainland Europe Interconnector gas pipeline at the end of 1998. They do not find any evidence of cointegration for the period after opening the Interconnector between 1998 and 2002. In contrast to Asche et al. [26], Panagiotidis and Rutledge [13] and Drachal [17] show that a long-run equilibrium relationship between U.K. gas and oil prices exists over the period 1996–2003. Panagiotidis and Rutledge [13] believe that the differences in results with Asche et al. [26] could stem from the inclusion of the electricity price in their study. These studies do not represent a general consensus on the relationship between crude oil and natural gas prices. This lack of consensus across studies is mainly due to either methodological or some other factors such as data, time period, and location of the study.

In recent years, some studies employ new empirical techniques to address the spillover effects between natural gas and crude oil markets in different time frequencies—see Batten et al. [27], Ji et al. [28], Perifanis and Dagoumas [29], Zhu et al. [30], Wang et al. [11], Li et al. [31], and Lovcha and Perez-Laborda [32]. To investigate the information or volatility spillover effect of the markets, they use more explanatory variables (e.g., historical events or disasters) with high-frequency data (e.g., daily data) from the financial sector. Similar to the studies that employ cointegration techniques, there is no consensus on the results of these studies. Many of them [27,29,30,32] argue that since the shale gas revolution in 2008, the spillover effect from the oil market to the gas market has disappeared or accounts for very small changes in the U.S., while before the shale gas revolution, the spillover effect was present episodically in some periods from the oil market to the natural gas market, or in some cases the effect was reversed. Wang et al. [11] show that the negative shock of the oil market did spill over sharply into the gas market. In addition, they argue that the effects of the shale gas revolution are not apparent in Europe.

Unlike the studies that focus on the relationship between oil and natural gas markets, there are limited studies that investigate the relationship between crude oil and other hydrocarbon markets. Oglend et al. [4] is the only study we are aware of in this strand. They investigate how the shale gas revolution has impacted the relationship between LPGs (namely, propane and butane), natural gas, and oil prices using a generalized cointegrated VAR model. They find that the expansion of shale gas has weakened the strong relationship between LPG and natural gas prices with crude oil prices in the United States. They argue that the state of the LGPs market affects the relationship between oil and gas prices. For instance, when high prices in the oil market increase the prices for liquids in LPG markets, then natural gas producers might increase the production of natural gas, aiming to gain more profits from the liquids, which, consequently, a higher supply of natural gas lowers its prices. However, there are other studies such as Westgaard et al. [33] and Myklebust et al. [34], who investigate the price dynamics of propane, butane, and naphtha traded in the north European market. They employ state-space models with unobservable components in a multivariate context to address the joint dynamics of these gas component prices. They do not incorporate natural gas or oil prices in their analysis to see how the prices might vary as the price of oil or gas fluctuates.

3.2. Oil Price as an Endogenous Variable

There has been considerable improvement in econometrics methods to identify the causes underlying oil price shocks in the last two decades. These studies are mostly built on Kilian [6]'s article, in which he shows how the price of oil is disengaged. Kilian [6] initiates an index to capture the changes in the real global economic activity and employs the structural Vector AutoRegressive (VAR) model to decompose the evolution of the real oil prices into three different sources: shocks to the global supply of crude oil, shocks to the global demand for all industrial commodities (including crude oil) that are driven by the global business cycle, and oil-market-specific demand shocks (also referred to as precautionary demand shocks). Since Kilian [6], the literature has departed from the earlier studies that mostly treat the price of oil as exogenous and incorporates supply and demand shocks to the real price of oil. Kilian's approach has resulted in the formation of new extensive literature to study the effects of the oil shocks. Some studies have examined the effect of oil price shocks on macroeconomic and financial variables. For more detail, see the review papers of Kilian [35] and Herrera et al. [36]. In this section, we review the studies that augment Kilian [6]'s structural VAR model to include the real price of hydrocarbons and investigate the response of the real price of hydrocarbons to the structural shocks in the crude oil market.

Jadidzadeh and Serletis [1] and Zamani [37] both augment Kilian [6]'s model and incorporate the real price of natural gas as the fourth variable to investigate the impact of those structural shocks in the oil market on natural gas prices. The former uses the monthly U.S. natural gas wellhead price from 1976:1 to 2012:12, and the latter uses the monthly U.S. natural gas imported price from 1989:1 to 2014:12. Both of these studies show that supply shocks in the oil market do not have a statistically significant impact on the real price of natural gas, but it increases the real price of natural gas after 12 months. The response of gas prices to the oil supply shocks measured by the impulse response functions are only statistically significant based on one-standard error bands. The demand shocks that are explained by an unexpected increase in the global demand for all industrial commodities have an immediate and sustained increase in the real price of natural gas.

Finally, expectations in the oil market captured by the precautionary demand for oil has an immediate and sustained increase in natural gas prices.

Jadidzadeh and Serletis [1] employ the forecast-error-variance decomposition to quantify the share of the oil market structural shocks on the variation of natural gas prices over different time horizons. They find that in the short-run the oil market shocks do not demonstrate a considerable effect on the variations in the real natural gas prices. For example, all three structural shocks account for less than one percent fluctuations in the real price of natural gas in the first month, while the contribution of the structural shocks increases as the forecast horizon increases. However, in the long run, 45% of the variation in the real price of natural gas originates from the three structural shocks in the crude oil market. The largest contributor to the variation in the real natural gas prices is the aggregate demand shocks (which explain more than 16% of the variation), followed by the contribution of precautionary demand shocks and oil supply shocks (accounting for about 16% and 13% of the variation, respectively) to the long-run variation in the real price of natural gas. The remaining variation (about 55%) in the real price of natural gas is from the shocks that are specific to the natural gas markets or generally other shocks.

A recent study by Jadidzadeh and Serletis [7] investigates the impact of structural shocks in the crude oil market on the price of ethane, propane, normal butane, isobutane, and natural gasoline over the period from January 1985 to April 2020. The results are very similar to what was presented in Jadidzadeh and Serletis [1] and Zamani [37] for natural gas prices. Although the supply-side shocks in the crude oil market do not demonstrate statistically significant impulse responses, a negative (one standard deviation) shock in the supply of crude oil would tend to increase each NGL's price after six months temporarily. A positive (one standard deviation) demand shock, either in the aggregate demand shock or the precautionary demand shock, represents an immediate and persistent increase in NGL prices. The forecast-error-variance decompositions show that in the short-run (first three months horizon), the oil market's structural shocks explain 23%, 34%, 44%, 50%, and 67% of the variation in ethane, propane, normal butane, isobutane, and natural gasoline prices, respectively. In the long run, the share of structural shocks accounts for approximately 55% of fluctuations in the prices of NGLs.

Unlike the studies that treat oil prices as exogenous and employ cointegration models, this stream of studies distinguishes the transmission channels that the price of oil impacts the other hydrocarbon prices. They presume that the system of equations in the SVAR model is composed of two blocks. The first block consists of the three structural shocks that are specific to the oil market, including oil supply shocks, aggregate demand shocks, and precautionary demand shocks. The second block captures the volatilities in the natural gas or NGLs markets that are not driven by the shocks in the oil market. Then, the model investigates how the structural shocks that are specific to the oil market impact the natural gas or NGLs prices.

4. Conclusions

We have provided a survey of studies that investigated the effect of crude oil price shocks on the main hydrocarbon prices. First, we discussed the channels through which oil price technically impacts natural gas and hydrocarbon gas liquids. We then reviewed two strands of studies. The first strand relies on the global nature of the crude oil market and presumes that large variations in the price of oil are historically driven by supply disruption as a result of political events and OPEC decisions. It assumes that oil prices are exogenous to macroeconomics variables and discards the source of oil price shocks in their analyses. It investigates the existence of correlation and the long-run cointegrating relationship between oil and hydrocarbon prices using different types of time series models such as Vector Error Correction Models. Initially, this literature shows that the relationship between the oil price and the natural gas or NGLs prices is asymmetric in a way that the oil price predominantly drives the other hydrocarbon prices, but not the other way around.

The second strand of studies treats the price of crude oil as endogenous and disentangles the causes underlying oil price shocks. This recent empirical literature, which is built on Kilian [6], employs a structural Vector AutoRegressive (VAR) model to identify the source of oil price fluctuations as a result of supply disruptions and demand changes in the integrated global oil market. Other studies augment Kilian [6]'s structural VAR model to include the real price of another hydrocarbon and investigate the response of other hydrocarbon prices to the structural shocks in the oil market. They show that oil supply-side shocks have a transitory and temporary impact while oil demand-side shocks have a persistent and permanent impact on other hydrocarbon prices. In addition, they show that about 50% of the variation in the other hydrocarbon markets is explained by the structural shocks in the global crude oil market in the long-run.

Author Contributions: Conceptualization, A.S. and A.J.; validation, A.S., A.J. and M.M.; investigation, A.J. and M.M.; writing—original draft preparation, A.J. and M.M.; writing—review and editing, A.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

HGL	Hydrocarbon Gas Liquids
LPG	Liquefied Petroleum Gases
NGL	Natural Gas Liquids
VAR	Vector AutoRegressive

References

1. Jadidzadeh, A.; Serletis, A. How does the U.S. natural gas market react to demand and supply shocks in the crude oil market? *Energy Econ.* **2017**, *63*, 66–74. [CrossRef]
2. Zavaleta, A.; Walls, W.; Rusco, F.W. Refining for export and the convergence of petroleum product prices. *Energy Econ.* **2015**, *47*, 206–214. [CrossRef]
3. Pindyck, R.S. Volatility in natural gas and oil markets. *J. Energy Dev.* **2004**, *3*, 1–19.
4. Oglend, A.; Lindbäck, M.E.; Osmundsen, P. Shale gas boom affecting the relationship between LPG and oil prices. *Energy J.* **2015**, *36*, 265–286. [CrossRef]
5. Hartley, P.R.; MedlockIII, K.B.; Rosthal, J.E. The relationship of natural gas to oil prices. *Energy J.* **2008**, *29*, 47–65. [CrossRef]
6. Kilian, L. Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *Am. Econ. Rev.* **2009**, *99*, 1053–1069. [CrossRef]
7. Jadidzadeh, A.; Serletis, A. Oil prices and the natural gas liquids markets. *Green Financ.* **2022**, *4*, 207–230. [CrossRef]
8. Wamsley, R.K. Natural gas liquid allocations. *Pet. Account. Financ. Manag. J.* **2000**, *19*, 1–16.
9. EIA. *Hydrocarbon Gas Liquids (HGL): Recent Market Trends and Issues*; Report; U.S. Energy Information Administration, U.S. Department of Energy: Washington, DC, USA, 2014.
10. Rui, X.; Feng, L.; Feng, J. A gas-on-gas competition trading mechanism based on cooperative game models in China's gas market. *Energy Rep.* **2020**, *6*, 365–377. [CrossRef]
11. Wang, N.; You, W.; Peng, C. Heterogeneous risk spillovers from crude oil to regional natural gas markets: The role of the shale gas revolution. *Energy Sources Part B Econ. Plan. Policy* **2019**, *14*, 215–234. [CrossRef]
12. Brown, S.P.A.; Yücel, M.K. What drives natural gas prices? *Energy J.* **2008**, *29*, 45–60. [CrossRef]
13. Panagiotidis, T.; Rutledge, E. Oil and gas markets in the UK: Evidence from a cointegrating approach. *Energy Econ.* **2007**, *29*, 329–347. [CrossRef]
14. Serletis, A.; Rangel-Ruiz, R. Testing for common features in North American energy markets. *Energy Econ.* **2004**, *26*, 401–414. [CrossRef]
15. Serletis, A.; Herbert, J. The message in North American energy prices. *Energy Econ.* **1999**, *21*, 471–483. [CrossRef]
16. Bachmeier, L.J.; Griffin, J.M. Testing for market integration crude oil, coal, and natural gas. *Energy J.* **2006**, *27*, 55–72. [CrossRef]
17. Drachal, K. Comparison between Bayesian and information-theoretic model averaging: Fossil fuels prices example. *Energy Econ.* **2018**, *74*, 208–251. [CrossRef]
18. Zhang, D.; Ji, Q. Further evidence on the debate of oil-gas price decoupling: A long memory approach. *Energy Policy* **2018**, *113*, 68–75. [CrossRef]

19. Hailemariam, A.; Smyth, R. What drives volatility in natural gas prices? *Energy Econ.* **2019**, *80*, 731–742. [CrossRef]
20. Yücel, M.K.; Guo, S. Fuel taxes and cointegration of energy prices. *Contemp. Econ. Policy* **1994**, *12*, 33–41. [CrossRef]
21. Hou, C.; Nguyen, B.H. Understanding the U.S. natural gas market: A Markov switching VAR approach. *Energy Econ.* **2018**, *75*, 42–53. [CrossRef]
22. Aruga, K. The U.S. shale gas revolution and its effect on international gas markets. *J. Unconv. Oil Gas Resour.* **2016**, *14*, 1–5. [CrossRef]
23. Barcella, M.L. *The Pricing of Gas*; Oxford Energy Forum: Oxford, UK, 1999.
24. Barton, A.; Vermeire, T.A.L. Gas price determination in liberalising markets: Lessons from the US and UK experience. In Proceedings of the British Institute of Energy Economics Annual Conference, Oxford, St. John's College, 20–21September 1999.
25. Heren, P. Removing the government from European gas. *Energy Policy* **1999**, *27*, 3–8. [CrossRef]
26. Asche, F.; Osmundsen, P.; Sandsmark, M. The UK market for natural gas, oil and electricity: Are the prices decoupled? *Energy J.* **2006**, *27*, 27–40. [CrossRef]
27. Batten, J.A.; Ciner, C.; Lucey, B.M. The dynamic linkages between crude oil and natural gas markets. *Energy Econ.* **2017**, *62*, 155–170. [CrossRef]
28. Ji, Q.; Geng, J.B.; Tiwari, A.K. Information spillovers and connectedness networks in the oil and gas markets. *Energy Econ.* **2018**, *75*, 71–84. [CrossRef]
29. Perifanis, T.; Dagoumas, A. Price and volatility spillovers between the U.S. crude oil and natural gas wholesale markets. *Energies* **2018**, *11*, 2757. [CrossRef]
30. Zhu, F.; Zhu, Y.; Jin, X.; Luo, X. Do spillover effects between crude oil and natural gas markets disappear? Evidence from option markets. *Financ. Res. Lett.* **2018**, *24*, 25–33. [CrossRef]
31. Li, X.; Sun, M.; Gao, C.; He, H. The spillover effects between natural gas and crude oil markets: The correlation network analysis based on multi-scale approach. *Phys. A Stat. Mech. Its Appl.* **2019**, *524*, 306–324. [CrossRef]
32. Lovcha, Y.; Perez-Laborda, A. Dynamic frequency connectedness between oil and natural gas volatilities. *Econ. Model.* **2020**, *84*, 181–189. [CrossRef]
33. Westgaard, S.; Faria, E.; Fleten, S.E. Price dynamics of natural gas components: Empirical evidence. *J. Energy Mark.* **2008**, *1*, 37–69. [CrossRef]
34. Myklebust, J.; Tomasgard, A.; Westgaard, S. Forecasting gas component prices with multivariate structural time series models. *OPEC Energy Rev.* **2010**, *34*, 82–106. [CrossRef]
35. Kilian, L. Oil Price Shocks: Causes and Consequences. *Annu. Rev. Resour. Econ.* **2014**, *6*, 133–154. [CrossRef]
36. Herrera, A.M.; Karaki, M.B.; Rangaraju, S.K. Oil price shocks and U.S. economic activity. *Energy Policy* **2019**, *129*, 89–99. [CrossRef]
37. Zamani, N. How the crude oil market affects the natural gas market? Demand and supply shocks. *Int. J. Energy Econ. Policy* **2016**, *6*, 217–221.

energies

Article

An Exploratory Study on the Development of a Crisis Index: Focusing on South Korea's Petroleum Industry

Kyungbo Park [1], Hangook Kim [2] and Jeonghwa Cha [3,*]

[1] Department of Business Administration, Andong National University, Andong-si 36729, Republic of Korea; warning@anu.ac.kr
[2] Division of Data Analysis, Korea Institute of Science and Technology Information, Seoul 02456, Republic of Korea; hgkim712@kisti.re.kr
[3] Department of Business Administration, Pusan National University, Busan 46241, Republic of Korea
* Correspondence: 71007591@naver.com

Abstract: Industrial crises exert considerable influence on a wide range of industries, national economies, and global economic landscapes. The primary objective of this study is to devise a crisis index specifically tailored for the petroleum sector—a vital component of South Korea's energy industry. An exhaustive analysis of the existing literature was conducted to extract pertinent elements and indicators, and indicator weights were determined using the analytic network process (ANP). Moreover, a combination of qualitative and quantitative methods was employed to rigorously evaluate the validity of the proposed crisis index. The implications derived from this study offer critical insights for stakeholders into the petroleum industry and demonstrate the potential applicability of a crisis index framework for other industries.

Keywords: energy industry; petroleum industry; crisis index

Citation: Park, K.; Kim, H.; Cha, J. An Exploratory Study on the Development of a Crisis Index: Focusing on South Korea's Petroleum Industry. *Energies* **2023**, *16*, 5346. https://doi.org/10.3390/en16145346

Academic Editors: Bernard Ziębicki and Edyta Bielińska-Dusza

Received: 30 May 2023
Revised: 7 July 2023
Accepted: 11 July 2023
Published: 13 July 2023

1. Introduction

Industrial crises are caused by specific and identifiable events [1]. As globalization spreads and technologies become more complex, inevitably, there is more potential to harm the industry. A crisis is defined as "a situation that threatens the high-priority goals of the decision making unit, restricts the amount of time available before the decision is transformed, and surprises the members of the decision making unit by its occurrence" [2] (p. 13). Thus, an industrial crisis threatens industry.

As the relationships among industries converge, a crisis in one industry is not just a crisis in a specific industry [3]. Crises in the energy industry that produces and sells energy have a great impact on the national economy and other industries [4]. The petroleum industry accounts for a large proportion of the energy industry, and, over several decades, it has become renowned for its substantial contribution to global economic development. The petroleum industry has facilitated socioeconomic growth and significantly influenced international politics. However, recent transformations in the energy market and technological advancements in manufacturing have led to a myriad of challenges within the oil industry, complicating the preservation of stability, and resulting in the emergence of multiple urgent crises. Factors such as geopolitical tensions, worldwide pandemics (e.g., the COVID-19 pandemic), shifting demands for energy resources, and the growing adoption of renewable energy to address climate change concerns have forged an unpredictable and volatile oil market.

Owing to these adversities, the oil industry has encountered various critical issues. These have included reduced energy demands, requisite transition to cleaner energy alternatives, and hazards associated with the industry's failure to adapt. Furthermore, the sector faces waning competitiveness because of outdated methods and practices coupled with insufficient investments. Thus, there is a necessity for proactive measures in response to rapid market changes. Additionally, unrecognized risks may lie dormant, potentially exacerbating existing issues within the industry.

The oil industry is substantially important for South Korea's national economy. The petroleum industry accounts for the largest proportion of Korea's energy industry, and it accounts for 1.5% of Korea's gross domestic product (GDP). In addition, the world's second, third, and fifth oil refineries are located in Korea. Several studies have demonstrated that Korea's petroleum industry affects the global economy [5–7]. In summary, a crisis in Korea's petroleum industry could damage the global economy, along with the country's domestic economy and industry. Under such circumstances, conventional risk management methods are insufficient, which necessitate the exploration of inventive and all-encompassing approaches to regulate various crises. Therefore, it is essential to establish a crisis index that can guide informed decision making and promote effective crisis management approaches. The development of a petroleum industry crisis index is of paramount importance for several key reasons. It enables identification of risks and vulnerabilities within the industry, allowing stakeholders to address these challenges proactively. Additionally, understanding the factors contributing to crises facilitates the establishment of strategies to enhance preparedness and resilience in the face of potential adversities. Furthermore, a crisis index would serve as a guide for government and regulatory policy decisions, ensuring adequate support for the industry during challenging times. Investors could also employ the index to make informed investment decisions based on industry stability and risk factors. Lastly, an index would provide a quantifiable measure to monitor trends and changes within the petroleum industry, offering valuable insights and prompting stakeholders to adapt their strategies accordingly. Collectively, these reasons underscore the crucial role a crisis index would play in fostering industry stability, growth, and long-term success within the context of the petroleum sector. Devising an index specifically for the petroleum industry would help stakeholders to utilize a quantitative metric to appraise and track risk levels, subsequently permitting the implementation of targeted interventions and optimal allocation of resources. Moreover, the creation of an evidence-based framework to assess industry-related risks would bolster the overall resilience and sustainability of the sector.

Despite the importance of understanding the risks associated with Korea's petroleum industry, there continues to be few studies on gauging its crisis levels. The Korean government, local authorities, and companies have developed indicators for predicting crises. However, due to possible concerns, these indicators are not openly disclosed; however, the leading economic index and coincident economic index are disclosed, but these are indicators for measuring the overall economic situation and not for evaluating industries. Furthermore, most evaluation standards predominantly assess financial status, which presents another limitation. Consequently, this study develops a crisis index tailored to South Korea's petroleum sector. Consequently, the extant literature was reviewed to extract the factors that influence the petroleum industry. This information was used to establish indicators constituting these influencing factors.

Adjusting the weight of each indicator is crucial for developing a crisis index. Therefore, we employed the analytic network process (ANP) to adjust the weights. Numerous preceding studies have employed the analytic hierarchy process (AHP) to adjust the weights of indicators when developing indices [8,9]. However, the ANP overcomes the limitations of the AHP and has recently been utilized in several index development studies [10]. In the analytic hierarchy process (AHP), a hierarchical structure is assumed, and the analysis is dependent on a single factor. In contrast, the analytic network process (ANP) presumes a network structure, enabling simultaneous consideration of interrelated factors, thus providing a more comprehensive approach. Additionally, each indicator is normalized to account for varying scales. Through these steps, we established a crisis index for the South Korean petroleum industry. Finally, we employed the Johansen cointegration test to evaluate the validity of the crisis index.

The remainder of this paper is organized as follows: Section 2 reviews Korea's petroleum industry and crisis indices used in previous studies, Section 3 introduces the research framework and describes the composition of each phase, Section 4 presents the analysis of the results, Section 5 summarizes the results and presents the implications and future research directions.

2. Research Background

2.1. The Petroleum Industry in Korea

Petroleum coupled with refined products is of immense importance globally. In addition to being a central energy source, refined petroleum products serve as feedstock for numerous other industries. Hence, they perform a mounting and pertinent part in the life of human beings by generating numerous jobs and noteworthy tax revenues and royalties, including foreign earnings, for local, state, and national governments [11].

The Korean petroleum industry has depended on domestic markets to meet the energy demands that are essential for economic growth. In the early stages of development, major energy equipment and technologies were imported due to limitations in indigenous technology and funding difficulties. However, over the past 40 years, Korea's energy industry has progressively acquired expertise and technology in areas such as refined petroleum product manufacturing, oil storage facility construction, and refinery operation through domestic development efforts. Consequently, Korea has attained economic advancement via its energy sector.

Although Korea is not an oil producer, it plays a significant role in the global oil refining market. In 2020, among over 500 refineries worldwide, three refineries ranked within the top five based on daily oil-refining capacity. These refineries included SK Energy Ulsan Plant (second place), GS Caltex Yeosu Plant (fourth place), and S-Oil Ulsan Plant (fifth place). As of November 2022, Korea's total exports amounted to USD 629.1 billion, with petroleum product exports contributing USD 58.221 billion (9.3%). Thus, Korea's petroleum industry has a considerable impact on its economy and other sectors.

As Korea lacks natural resources, it relies primarily on the import of oil and other raw materials. Therefore, an early warning system for the oil and raw material markets is essential to monitor rapid increases in the prices of crude oil or raw material. The indicators used in the model include U.S. crude oil inventories, OPEC's crude oil production, variables related to economic fluctuations, and futures contracts for crude oil [12].

However, the existing early warning system merely focuses on oil prices and does not represent a crisis in the petroleum industry.

2.2. Research Related to a Crisis Index

Several studies have investigated crises in the petroleum industry and crisis indices in many areas. In addition, research has also been conducted on a resilience index. Table 1 summarizes the existing studies on crisis and resilience indices. The methodology used in these studies included natural networks, regressions, and formulas created by the researchers. In addition, in all the studies, the elements necessary for the index were set based on the existing literature and the factors and indicators were set based on research in the literature research. The existing research has analyzed data spanning from a minimum of one year to as long as 23 years, generating a crisis index as a result. The primary focus has been on financial risk indices, with recent studies shifting towards resilience. Furthermore, many investigations have endeavored to represent the crisis through a minimal number of variables. The methodology has ranged from utilizing established models to developing new formulas to more accurately depict the crisis index. In summary, risk index-related studies have primarily concentrated on financial aspects, while more recent research has explored resilience. Several studies have also attempted to measure the crisis by devising innovative formulas. Therefore, this study attempts to identify the factors affecting the Korean petroleum industry based on previous studies.

Table 1. Extant literature on a crisis index.

Study	Created Index	Data Period	Major Indicators	Methodology
[13]	Financial conditions index (FCI) for the euro area	2003–2011	▪ Monetary policy variables ▪ Price variable ▪ Non-financial loans ▪ 3-month Euribor rate and EONIA ▪ STOXX index ▪ Bank lending survey	▪ Principal component analysis models
[14]	Stock market instability index (SMII) for Korean stock market	1994–2003	▪ Stock market index	▪ Artificial neural networks ▪ Stability-oriented approach (SOA)
[15]	Risk Monitor CDM Model	1980–2002	▪ 4 Annual indicators ▪ 12 Quarterly indicators	▪ 5 Modern non-parametric classification methods (neural network, SVM, random forest, bagging algorithm)
[16]	Regional industrial resilience	1993–2006	▪ 8 Variables (human capital intensity, total regional employment, the regional specialization in ICT, etc.)	▪ Regression
[17]	Resilience index	1997–2011	▪ 10 Attributes (export diversity, private debt, governance, etc.)	▪ Formula
[18]	Regional resilience	2001–2007	▪ 4 Attributes (vulnerability, resources, adaptive capacity, and policies)	▪ Discriminant function analysis ▪ Regression
[19]	U.S. county economic resilience	2007	▪ 11 Variables (employment, income, etc.)	▪ Network Analysis ▪ Generic input–output table
[20]	Industrial resilience	2007–2009	▪ Full-time employees ▪ Part-time employees ▪ 2 Aspects (quantity and quality)	▪ Formula

3. Research Framework

The purpose of this study is to produce a crisis index for the Korean petroleum industry and to compare it with the crisis index produced by major events. Therefore, we proposed a research framework (Figure 1) to achieve the purpose of this study. The research framework comprises three phases.

In Phase 1, factors affecting the Korean petroleum industry and the indicators included in these factors were identified. Subsequently, we constructed and administered a questionnaire. In Phase 2, the weight of each indicator was calculated based on the survey data. We also collected and normalized data related to the indicators. Through this process, we developed a crisis index for the Korean petroleum industry. In Phase 3, the crisis index's relevance was evaluated by comparing it with major events.

3.1. Phase 1: Performance Measurements

The initial phase employed a performance measurement (PM) extraction method in conjunction with a cause-and-effect diagram to reveal the causal relationships among critical crisis factors (CCFs). Most prior research pertaining to crisis indices within economic or industrial domains has focused on singular aspects of industrial crises, such as global or domestic economic conditions. To evaluate a crisis index that is integrated within the process instead of serving as a means of simplistic measurement, PMs should be extracted from each economic condition, and CCFs should be correspondingly interconnected. Thus, a cause-and-effect relationship was employed to derive the perspectives and CCFs.

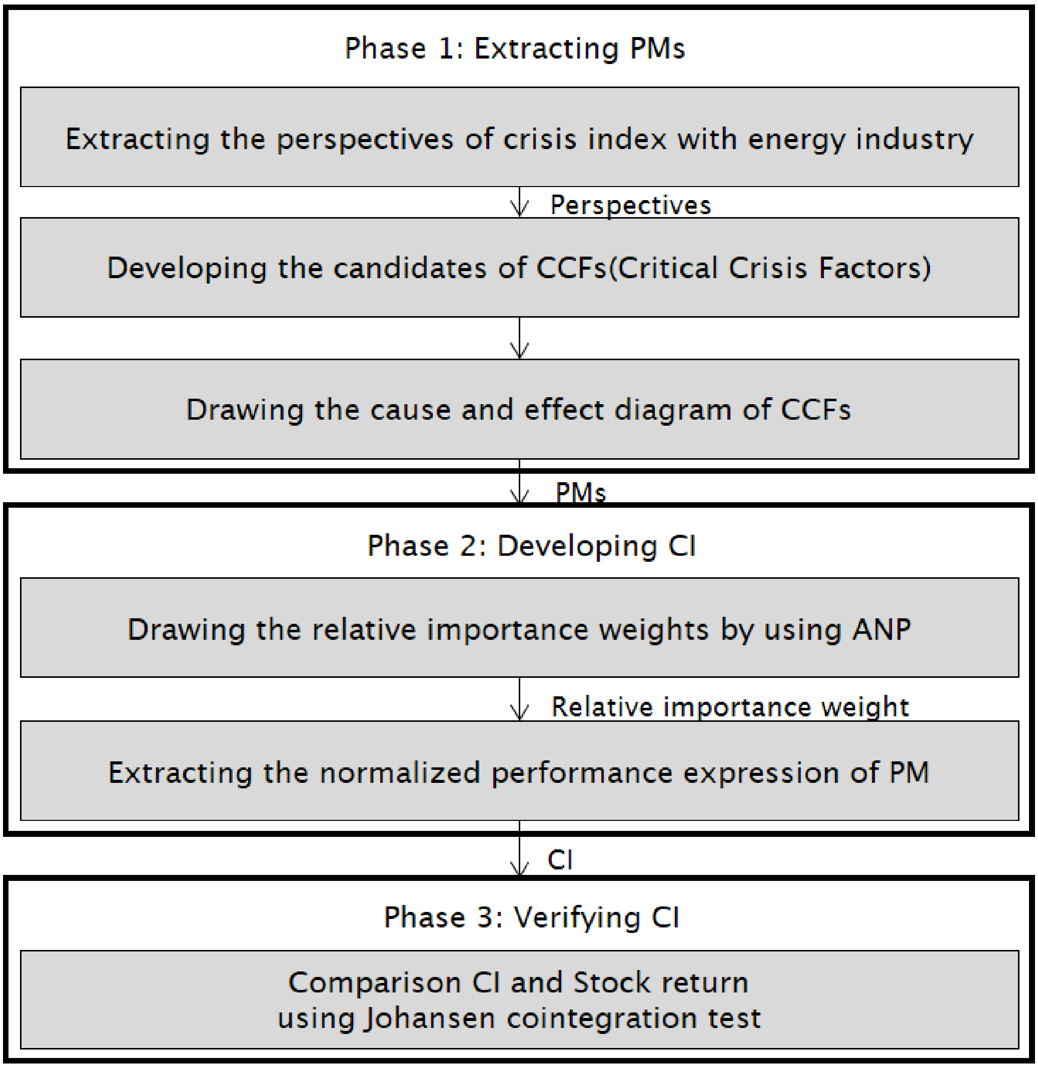


Figure 1. Research framework.

Because the PMs extracted from Phase 1 exhibited different measurement units, it was important to apply a normalization method. Given the varying weight of each PM and their inherent causal relationships, the analytic network process (ANP) proved to be an appropriate choice. By utilizing normalization and aggregation techniques, it was feasible to compute normalized scores according to each perspective.

3.1.1. Extracting the Perspectives for Developing a Crisis Index for the Energy Industry

Establishing perspectives for developing a crisis index is important for several reasons. First, perspectives provide a structured and well-defined framework that allows for a systematic approach to analyze the complexities associated with an industry's performance [21]. This well-organized methodology ensures that all relevant variables are considered, while assessing the potential risks and vulnerabilities faced by organizations within the industry. Second, by delineating critical perspectives, executives and decision makers can better understand the driving forces and external conditions that shape an organization's performance and susceptibility to crises. This comprehensive understanding enables them to identify the root causes of potential threats, and consequently, to develop more targeted and effective response strategies to mitigate the adverse impacts of such events. Third, establishing well thought out perspectives facilitates the monitoring and tracking of changes within an industry and the various factors influencing the changes. Ongoing monitoring is essential for early identification and accurate forecasting of potential crises, which can help organizations to prepare and adapt proactively. Fourth, perspectives offer valuable insights into how different aspects of an industry are interconnected and mutually influenced by one another. A holistic understanding of the relationships among these factors enables decision makers to identify potential synergies and leverage points to maximize an organization's resilience and performance even amid crises. Finally, distinct perspectives for developing a crisis index promote the prioritization of critical factors according to their relative importance and impact on the industry. By focusing on the most pertinent and influential factors, stakeholders can strategically allocate their resources and efforts to effectively address the most pressing challenges, thereby enhancing an organization's overall robustness and crisis preparedness.

In conclusion, establishing the perspectives for developing a crisis index is essential to provide a structured approach for understanding the intricacies of managing industry crises, identifying and addressing potential threats, monitoring ongoing changes, analyzing interrelationships among factors, and prioritizing critical aspects to ensure an organization's resilience and success during crises. This approach can significantly improve the effectiveness of management decisions and strategies to address industry-related challenges. Numerous approaches have been used to develop industry-related risk indices. Specifically, the extant literature mentions three perspectives, i.e., global economic conditions, domestic economic conditions, and industry conditions.

3.1.2. Developing the Candidates of Critical Crisis Factors (CCFs)

Prior research has identified three major categories of perspectives for developing an industry crisis index. However, previous studies have lacked a comprehensive survey of factors that affect a crisis index. Hence, this phase endeavored to achieve greater realism and precision by identifying critical crisis factors (CCFs) and mapping their interrelationships based on causal relationships. This phase utilized the existing research to ascertain CCFs while considering the three perspectives derived in the preceding step [22]. Relationships among CCFs were established using the causal connections among identified factors. Further, CCFs unrelated to the industrial crisis index were excluded from the study.

Rockart [22] defined CSF as "a limited number of components that can ensure an organization's ability to compete successfully if the outcome is satisfactory". They developed the "CSF method", which was intended to help executives to understand the factors that create essential and potential competitive advantages [22,23]. However, in this study, we extracted the factors that affected the crisis of the industry; thus, these factors were denoted as CCFs and not CSFs. CCFs are defined as "a limited number of components that can measure the risk of an industry".

3.1.3. Drawing Cause and Effect Diagram of Critical Crisis Factors (CCFs)

Economic revitalization and industrial productivity display a virtuous cycle structure, emphasizing the interconnectedness and reciprocal nature of these elements in fostering growth and progress [24]. While there is notable heterogeneity between a state and its industry, most relationships between economic situations and industry-specific conditions exhibit positive correlations. This underscores the importance of carefully analyzing domestic economic indicators to accurately assess the situation in sectors such as Korea's petroleum industry [25].

When evaluating the prospects of a crisis within an industry, it is essential to consider domestic as well as global economic factors because of their far-reaching impacts on businesses and markets. However, focusing solely on these external macroeconomic aspects may not provide a complete understanding of the challenges faced by industries. Therefore, it is imperative to examine an industry's internal dynamics to gain a comprehensive perspective of its overall stability and potential risks [26]. This multifaceted approach ensures that strategies developed to address potential crises are well informed and effective in addressing the unique challenges of each industry.

3.2. Phase 2: Developing the Crisis Index (CI)

The objective of this phase was to identify the factors and indicators influencing the domestic petroleum industry. Subsequently, weights were assigned to each indicator using the analytic network process (ANP) methodology. Finally, a crisis index was developed by incorporating the assigned weights. This index offers a comprehensive assessment of the industry's potential vulnerabilities.

3.2.1. Drawing the Relative Importance of Weights Using the Analytic Network Process (ANP)

The analytic network process (ANP) [27] is a comprehensive decision-making technique that can include all relevant criteria that potentially affect decision making. The AHP serves as the starting point for ANP. The advantages of the AHP in group decision making are as follows [28]: First, tangible and intangible, that is, individuals and shared values, respectively, should both be included in the decision-making process. Second, in-group discussions may focus on objectives rather than alternatives. Third, the discussion should be constructed such that all factors related to the decision are considered. Fourth, in a structured analysis, the discussion should continue until each member of the group considers the relevant information and reaches an agreement. In addition to the advantages of AHP, the ANP provides a more generalized decision-making model without assuming the independence of lower- and within-self-level elements. Among the different criteria levels, bidirectional arrows or arcs graphically represent the interdependence of the ANP models. If interdependencies exist at the same level of analysis, loop arcs can be used to indicate these interdependencies. Further, a questionnaire was developed based on the extracted factors and indicators. In this study, the ANP was used to calculate the weight of each indicator. Table 2 indicates the ANP questionnaire used for calculating the weights. In this study, factors and indicators to be extracted through the subsequent process were compared.

Table 2. Example of the ANP questionnaire.

The Question Is Which One Is Important and How Much?																		
Indicator	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Indicator
Indicator 1																		Indicator 2
Indicator 1																		Indicator 3
...																		...
Indicator n − 1																		Indicator n

The AHP cannot consider the interrelationships among elements [29]. Consequently, the ANP is an advanced version of the AHP that considers the internal relationships among elements through additional steps [30].

The ANP does not require a hierarchy but rather a network of elements. In this network, the elements are considered to be nodes of a number of clusters, and the level of each node may both be dominant and be dominated in pairwise comparisons [31]. Assume that each cluster k, k = 1, . . . , m, includes n_k elements eK1, . . . , eKnk. These elements can be used to build a supermatrix, Figure 1, and compared using Saaty's scale.

After comparing all the elements in the supermatrix, it is increased to any large constraint to obtain the cumulative effects of the elements on each other [32]. The supermatrix considers all possible relationships among elements.

3.2.2. Extracting the Normalized Performance Expression of Performance Measurements (PMs)

In this study, indicator data were collected from several sources. Therefore, the scale for each indicator was set differently. Therefore, normalization was performed for each indicator. The goal of normalization was to ensure that all the data points were reflected on the same scale (importance).

In several studies, normalization has been used to integrate indicators with different units and ranges of characteristics [33]. Therefore, this study normalized the different indicators.

The crisis index was generated based on the weights and data extracted using the above process. The crisis index (C.I.) was created using Formulas (1) and (2) below, where B.I. is the interim Business Index of the industry, NI_i is the ith normalized indicator value, and W_i is the weight of the ith indicator:

$$\text{B.I.} = \sum NI_i * W_i, \tag{1}$$

$$\text{C.I.} = 100 - (\text{B.I.} - 100), \tag{2}$$

3.3. Phase 3: Evaluating the Crisis Index (C.I.)

Two methods were used to evaluate the developed crisis index. The first method evaluated the crisis index by comparing it with major events. We determined whether the C.I. proposed in this study was related to major events. Major events were identified from an article on the petroleum industry. The second method evaluated the crisis index by comparing it with the stock yield. For evaluation, the two indices were compared using the Johansen cointegration test [34]. Several studies have used stock returns as a representative index to determine the conditions of an industry [35–37]. The Johansen cointegration test is a method for verifying the existence of a stable and long-term balance between integrals through hypothesis verification of the vector autoregressive (VAR) model. The Johansen test can be considered to be a multivariate generalization of the augmented Dickey–Fuller test. Generalization refers to the examination of linear combinations of variables for unit roots. The Johansen test and estimation strategy—maximum likelihood—make it possible to estimate all cointegrating vectors when there are more than two variables [38].

The Johansen cointegration test is a pivotal statistical technique for discerning the cointegrating relationships among a multitude of nonstationary time series variables. Because of its efficacy in determining the existence of long-run equilibrium relationships among the scrutinized variables, this test has garnered considerable recognition among researchers engaged in economic and financial time series analysis [38]. By adopting a system-level approach, the Johansen cointegration test elaborates on the foundation of VAR models that simultaneously consider the interdependence of diverse variables [34]. The incorporation of VAR models enables the test to capture complex interrelationships among time series variables, thereby enabling researchers to unveil the fundamental patterns and associations embedded within the data. Moreover, the Johansen cointegration test encompasses two distinct test statistics: the trace test and the maximum eigenvalue test. Each of these tests examines the presence of cointegrating relationships at distinct vantage points. The use of these complementary tests enhances the reliability of the research findings and provides a comprehensive perspective on cointegration relationships. In conclusion, the Johansen cointegration test serves as a critical instrument for exploring the long-run equilibrium connections among non-stationary time series variables. Its foundation in the system-level approach, which is predicated on VAR models coupled with the provision of two supplementary test statistics, makes this method an invaluable resource for researchers seeking insights into the intricate dynamics and interdependencies that dictate the long-run trajectory of the variables under investigation. Because of its versatility and robustness, the Johansen cointegration test remains a highly acclaimed and indispensable tool in econometrics and applied time series analysis.

Thus, these two processes were used to validate the proposed index.

4. Result

4.1. Phase 1: Extracting Performance Measurements (PMs)

4.1.1. Extracting the Perspectives for Developing a Crisis Index for the Energy Industry

Based on the extant studies, the perspectives on the crisis in the Korean petroleum industry can be divided into three categories. First, global economic factors are classified into the first category, which includes the exchange rate, global supply chain management, international raw material prices, U.S. economic conditions, and the export/import status of Korea's major trading partners,.

Second, domestic economic factors comprise the second category, which includes the composite economic, sentiment, price, import/export, and industrial production indices. Finally, industrial economic factors comprise the third category, which includes the employment, shipment, and business survey indices. Table 3 summarizes the perspectives and factors for developing the crisis index.

Table 3. Perspectives for developing the crisis index.

Perspective	Factor	Reference
Global Economic Conditions	Exchange rate	[39–43]
	Global supply chain	[44–51]
	Commodity	[48–57]
	U.S. Economic condition	[58–69]
	Main exporter and importer	[70–74]
Domestic Economic Conditions	Economic fluctuations	[75–78]
	Sentiment index	[79–82]
	Price related	[83–89]
	All industry activity	[90–92]
	Trade activities	[93,94]
Industry conditions	Employment	[95,96]
	Industry shipments	[97,98]
	Industry perception	[99]

4.1.2. Extracting the Candidates of CCFs

In previous studies, many researchers have analyzed the variables that affect industries. Many variables affect the industry, but they are largely divided into global economic conditions [100,101], domestic economic conditions [102,103], and industrial conditions [104,105].

1. Global economic conditions

Owing to recent globalization, the global economy has significantly influenced countries and companies [100]. The global economy is a factor for countries and companies with significant imports and exports [106]. Global economic conditions are significant to understand the industrial crisis because the Korean petroleum industry generates large profits from exports.

- Exchange rate

Exchange rate is an important macroeconomic variable used to determine international competitiveness [39]. Foreign exchange risk implies that changes in exchange rates affect a company's cash flow and values [40]. An oil-exporting (importing) country may experience currency appreciation (depreciation) in response to rising oil prices and currency depreciation (appreciation) in response to falling oil prices [41]. The exchange rate affects the price of imported crude oil, which, in turn, affects the price of petroleum product prices [42]. An increase in the exchange rate raises industrial profits related to petroleum in the short term; however, in the long term, the impact is reduced by the feather and rocket effect [43]. In summary, exchange rate fluctuations are important determinants of the petroleum industry's crisis.

- Baltic Dry Index

The international dry bulk shipping market is closely related to commodity and crude oil markets [44]. At the same time, the Baltic Dry Index (BDI) is usually considered to be a major economic indicator [45]. The Baltic Dry Index (BDI) comprises average prices paid for the transport of dry bulk materials across more than 20 routes [46]. Rising oil prices cause shipping companies to increase their expenditures on fuel costs, that is, crude oil is a fuel that directly affects the cost of shipping [45]. Thus, rising oil prices affect shipping fares. This, in turn, further increases the price of crude oil. An increase in the BDI negatively affects the petroleum industry. In Korea, crude oil is imported and refined petroleum products are exported. An increase in shipping costs negatively affects product price competitiveness. This would cause a crisis in the industry.

- Global Supply Chain Pressure

The Federal Reserve Bank of New York developed the Global Supply Chain Pressure Index (GSCPI) to measure the common factors of several cross-country and global indicators of supply chain pressure. The GSCPI indicates that supply chain disruptions are about a mismatch between demand and supply, indicating a lack of balance. A mismatch between demand and supply causes negative supply shocks. Supply shocks cause a decrease in production capacity, and therefore, increase the economic burden of companies [47]. In other words, an increase in the GSCPI will negatively impact the petroleum industry. In particular, Korea imports most of its crude oil supply from the Middle East; therefore, supply imbalances caused by supply chain pressure will negatively affect Korea's petroleum industry.

- Crude oil price

Several studies have suggested that rising oil prices shrink the economy [48–50]. An increase in the absolute crude oil price, and not an increase in price due to an exchange rate rise, may also negatively affect consumption, investment, and unemployment [51]. Additionally, increasing costs of firms affects the postponement of investment decisions [51]. A prolonged increase in oil prices could lead to changes in the production structure and have a deeper impact on unemployment [50]. Indeed, an increase in crude oil prices reduces the returns on sectors that are oil intensive and incites firms to adopt and construct new processes that are require lesser oil inputs [107,108]. This change generates capital and labor reallocations across sectors that can affect unemployment in the long run [52]. In summary, an increase in absolute crude oil prices will negatively affect the petroleum industry in the long and short terms.

- Commodity price

Commodity prices can provide instantaneous information on the state of the economy [53]. Moreover, because many primary commodities are important inputs for the production of manufactured goods, changes in commodity prices directly affect production costs [54]. Increasing production costs reduce a company's revenue and productivity [55]. This situation can lead to an industry-wide recession that reduces energy consumption [56]. The Bloomberg Commodity Index (BCOM) is a representative index of the price of international commodities. It is calculated on an excess return basis and reflects commodity futures' price movements.

- Gold price

In the past, gold was considered to be a means of risk hedging; however, now it is also a financial investment product. In addition, when the economy grows, each country's central bank develops a strategy to increase gold holdings [57]. Gold is a precious metal with a risk-hedging function that enables predictions of macroeconomic variables and economic activity [109]. In other words, gold is an indicator of the state of an economy, which represents energy consumption.

- U.S. economic situation

Many studies have shown that Korea's economy is subordinate to the U.S. economy [58]. Export-oriented economies such as Korea and Japan are closely related to the accumulation of foreign exchange reserves, which are affected by the USA [59]. In addition, because the USA is Korea's main export destination, its economy is affected by the U.S. economic situation [60,61]. Therefore, the U.S. economy is an important variable for the petroleum industry, which produces energy sources. A set of variables representing the U.S. economy includes the U.S. Industrial Production Index [62,63], U.S. standard interest [64], U.S. money stock [65,66], U.S. economic policy uncertainty [67], and the Dow Jones Index [68,69].

- Korea's main exporter and importer

Korea's ratio of exports and imports to GNI is relatively high compared to that of other countries. According to the OECD, Korea's ratio of exports and imports to GNI is 72.3%, compared to 31.4% for the USA, 37.5% for Japan, and 66.1% for France. This means that Korea has a trade-dependent economy [70]. The Korean economy shows a positive correlation with imports, which are a major factor in evaluating the revitalization of the economy [71]. Export performance and expansion represent economic growth and economic conditions [110]. First, higher exports ease the foreign exchange constraint, and higher imports of capital goods and intermediate goods are permitted [71]. Second, the home country can concentrate its investment in sectors in which it enjoys a comparative advantage [72]. Third, the addition of international markets provides scope for economies of scale in the export sector [71]. As of 2022, China (21.9%), the USA (13.5%), and Vietnam (6.1%) accounted for 41.6% of Korea's total imports and exports. Imports and exports to the top three countries mentioned above greatly influence the Korean economy [73,74]. Japan has been South Korea's primary trading partner. However, since 2013, there has been a notable shift in Korean exports to Vietnam. As of 2022, the income discrepancy has more than doubled, reflecting a significant change in trading dynamics. Furthermore, the European Union (EU) indicators do not accurately represent those of each individual member country, as considerable disparities exist within the EU. The export and import indicators of these EU member nations are notably lower than those of China, the United States, and Vietnam.

2. Domestic economic conditions

Economic vitalization and industrial productivity have a virtuous cycle structure [111]. There is heterogeneity between the state and industry; however, most of the relationships between the economic and industrial situations are positive [112]. In other words, the domestic economic situation reflects Korea's petroleum industry.

- Economic fluctuations

Many countries have created indices to evaluate their economic conditions [75], such as the business indicator index that represents Korea's real economy [76]. Several studies have used composite indices (CIs) to reflect Korea's economic situation [77,78]. CIs are summary measures designed to indicate changes in the direction of aggregate economic activity. Composite indices examine and predict the overall direction of economic change, speed of change, economic situation, and turning points in economic conditions by selecting, processing, and integrating major indices to reflect each part of the economy. Composite indices measure not only directions, phases, and turning points, but also amplitudes and levels in the economy. The CI consists of the composite leading index, composite coincidence index, and composite lagging index. The composite leading index indicates cyclical turning points in economic activity. Composite coincident index includes turning points that coincide with those of the business cycle. Subsequently, the composite lagging index confirms economic activity.

- Sentiment index

The effects of a survey-based consumer sentiment index (CSI) and economic sentiment index (ESI) as leading indicators of the actual economic situation have been confirmed, and CSIs and ESIs are actively used in policy judgment and decision making in many countries [79]. Previous studies have shown that a survey-based consumer sentiment index (CSI) is an effective leading indicator of real economic conditions [80,81]. A CSI offers valuable insights into the prevailing economic climate by monitoring the present state of the economy and signaling potential shifts in economic activity. In South Korea, the Bank of Korea (BOK) publishes a monthly CSI, aiming to capture both the emotional and the economic factors that influence consumer behavior. This is achieved by surveying households regarding their perceptions of current and future economic conditions, at the individual level as well as the national level. An economic sentiment index (ESI) is a survey-based index that provides information on the perceptions and expectations of economic agents, both from the demand (consumers) and the supply (producers) sides of the economy [82].

- Price-related index

A price index is the normalized average price of relatives for a given class of goods or services in a given region during a given time interval. Previous studies have used the benchmark interest rate [83,84], expected inflation rate [85,86], and producer price index [87,88] as indicators of the price index.

Increasing the benchmark interest rate increases interest rates in the market, thereby widening the gap between domestic and overseas interest rates and increasing the inflow of foreign capital into a country [87]. Consequently, the exchange rate and import prices fall, which further reduce domestic prices. In other words, the benchmark interest rate and inflation are negatively correlated. Interest rates alter firms' financing costs, affect the amount of loan interest and principal payments, and affect the cash flows of firms [90]. A decline in cash flows negatively affects an industry [91]. However, the effect of the benchmark interest rate varies across industries [90].

Real interest rate and expected inflation are two key economic variables [92]. Real rate variation should only affect the short end of the term structure, whereas the variation in long-term interest rates is primarily affected by shocks to expected inflation [36]. Therefore, the expected inflation rate was used to identify long-term changes [113]. Expected inflation rates also apply to perceived inflation rates [114]. However, the effect of the expected inflation rate varies across industries [115].

The producer price index (PPI) is an indicator that calculates the average cost of a collection of inputs frequently used by manufacturers. The PPI serves dual purposes: (1) offering price indices for deflating gross domestic product data and (2) presenting a comprehensive measure of inflation levels. Many economists believe that the PPI can function as a reliable predictor of upcoming consumer inflation since fluctuations in the prices paid by producers (i.e., shifts in production costs) typically occur prior to changes in consumer costs [87]. The effect of the PPI differs across industries [89]. However, the PPI is disadvantageous in that it includes all items corresponding to raw materials, intermediate goods, and final goods, because domestic shipments, including intermediate transactions between companies, are selected as populations and weighted. Therefore, Korea developed a domestic supply price index. The domestic supply price index was divided into raw materials, intermediate goods, and final goods according to the degree of processing, including not only domestic shipments but also import and export price index. Consequently, it is possible to understand the ripple process of prices step by step.

- All industry activity

Industry activity is fundamental to the economic value and situation [116]. Industrial activity is useful because it determines the current economic situation. Korea developed the Index of All Industry Production (IAIP) to understand industry activities. The IAIP is a single index that aggregates monthly production activity trends for goods and services across all industries in the entire Korean economy.

- Trade activities

Global and domestic economic situations are closely related [93]. Trade has a strong positive effect on economic growth, and trade activation confirms a positive national economic situation [94]. Several studies have confirmed that imports and exports are closely related to the economy. Active exports indicate that the overseas economy is booming, leading to vitalization of the domestic industry. Active imports mean that many raw materials are being invested in because of the vitalization of the domestic industry. In other words, export and import activities imply that the domestic economy is booming.

3. Industry conditions

To understand the crisis in the industry, it is necessary to examine the industry's internal situation [104] along with assessing the global and domestic factors.

- Employment

Employment growth is a useful indicator of an industry's location. If an industry's performance decreases, employment naturally decreases [95]. If the forecast for industrial production is good, then creation of employment and new employment increase [96]. In other words, employment and new employment are excellent indicators of the industry's situation.

- Industry shipments (manufacturing shipment)

Industrial shipments are attractive variables for monitoring industrial situations [97]. Industry shipments relate to the vitalization of an industry [98]. Korea developed an Index of Manufacturing Shipment (IMS) to indicate the level of shipment. The IMS represents the level at which goods are sold at the factory where they are produced. The IMS is a useful index for checking the inventory of industries. Rinsing inventory rates present a negative signal for the industry.

- Industry perception

These indices are considered to be the most representative of these industries and are quantitatively evaluated through quantified features. However, industry perceptions may differ from those used to evaluate current industries' performances.

Therefore, several countries use a business survey index (BSI) to examine the current situation in the industry. The business survey index (BSI) was compiled to understand the business conditions for the current month and their outlook for the following month by conducting surveys on entrepreneurs' perceptions. A BSI is commonly used in application forecasting. The existing academic literature also demonstrates that a BSI is a powerful tool for forecasting and tracking economic activity [99]. In Korea, 15 items, including business conditions, sales, and profitability, were surveyed among 3255 corporations that were selected using stratified systematic sampling and fall into the following classifications as per the 10th revision of the Korean Standard Industrial Classification (KSIC). The bulk of business surveys is useful because they provide leading indicators for the most obvious macroeconomic aggregates [99]. This information is summarized in Table 4. The data presented in Table 4 were obtained from the National Statistical Office of Korea and index-related organizations in the United States. The economic policy uncertainty index and the Dow Jones Index were sourced from previous studies, ensuring consistency and accuracy.

4.1.3. Drawing the Cause-and-Effect Diagram of Critical Crisis Factors (CCFs)

We extracted three perspectives and 13 CCFs from the extant literature. Based on this information, we illustrated the cause-and-effect diagrams between the identified perspectives and CCFs. In the cause-and-effect relationship diagram, CCFs of the crisis index are categorized as leading and lagging factors, and the relationships are presented in ascending order. The cause-and-effect relationship between the leading and lagging CCFs is illustrated in Figure 2. The leading and lagging factors were developed through a comprehensive analysis of prior research.

Each perspective is directly associated with the crisis potential of an industry. Global and domestic economic conditions both influence an industry's economic performance. In the causal relationship diagram, CCFs are categorized as antecedent factors, and their relationships with lagging factors are depicted in ascending order to highlight the intertwined nature of these elements.

Table 4. Factors and indicators affecting the industry crisis.

Factor 1	Factor 2	Indicator
Global Economic Conditions	Exchange rate	KRW/USD
	Global Supply Chain	Baltic dry index
		Global supply chain pressure
	Commodity	Crude oil price
		Bloomberg Commodity Index
		Gold price
	U.S. Economic condition	U.S. Industrial Production Index
		U.S. money stock
		U.S standard interest
		U.S. economic policy uncertainty
		Dow Jones Index
	Main exporter and importer	Export/import to U.S.
		Export/import to China
		Export/import to Vietnam
Domestic Economic Conditions	Economic fluctuations	Leading Index
		Coincident Index
		Lagging Index
	Sentiment	Economic Sentiment Index
		Consumer Sentiment Index
	Price related	Benchmark interest rate
		Expected inflation rate
		Domestic supply price index
	All industry activity	Index of All Industry Production
	Trade activities	Total export
		Total import
Industry conditions	Employment	Employment
		New employment
	Industry shipments	Export
		Domestic
	Industry perception	Performance
		Forecast

4.2. Phase 2: Developing a Crisis Index (C.I.)

4.2.1. Drawing the Relative Importance of Weights by Using the Analytic Network Process (ANP)

A total of 20 professors related to the industry were surveyed to establish weights. After explaining the crisis to 20 professors, they were asked to participate in the survey. The content of the questionnaire was set as "This questionnaire is related to the industrial crisis index. Regarding the crisis, you can fill in the position where you think item element-1 is 'very important' compared to item element-2.". We used Super Decisions Software (Ver.2.10) to calculate the ANP to produce an unweighted supermatrix and a weighted supermatrix. These two matrices were multiplied by a convergent dependency relationship to obtain the relative weight of each element. The correlations between the ANP assessment factors and indicators are shown in Figure 3, and the final results are listed in Table 5.

4.2.2. Extracting the Normalized Performance Expression of Performance Measurements (PMs)

The data used in this study were collected between January 2012 and April 2022. Data for each indicator were collected, and the units of each data point were normalized because they did not match. Because most of the indices released in Korea were based on 2015 = 100, other indices were also set to 100 in 2015. All indicators were derived as values relative to the average value in 2015 and normalized. The normalized equation is as follows, where I_i is the ith indicator:

$$NI_i = \frac{I_i}{\left(\sum_{l=1}^{12} I_{i2015}\right)/12} * 100, \quad (3)$$

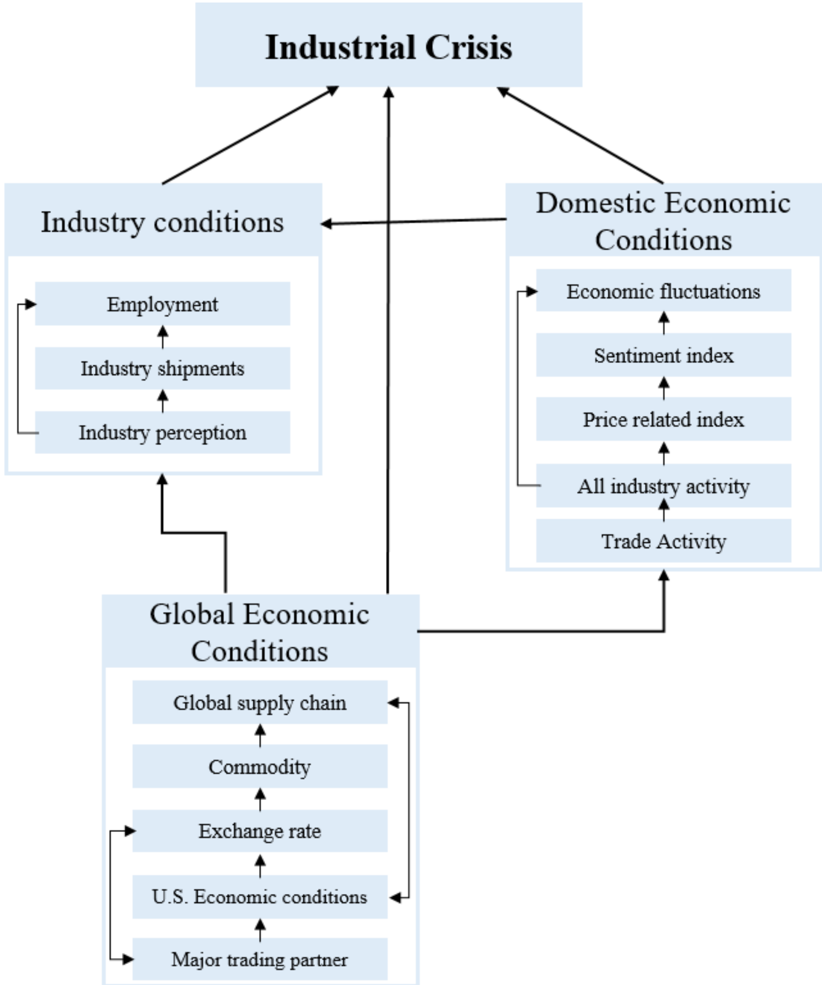


Figure 2. The cause-and-effect diagram of CCFs.

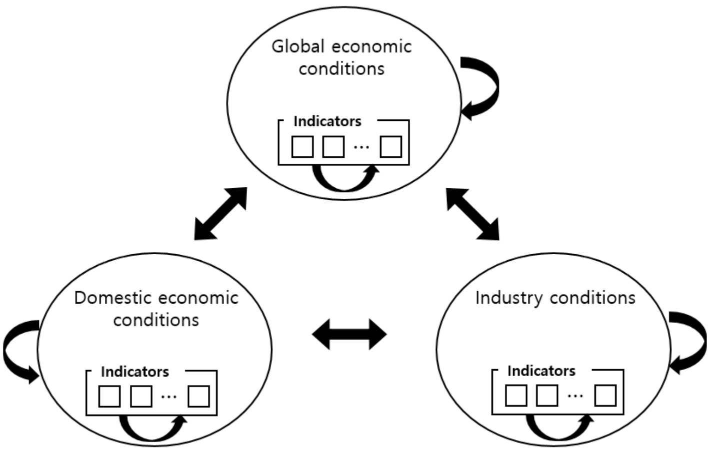


Figure 3. ANP assessment factors and indicators.

Table 5. Weights of indicators evaluated using the ANP.

Factor 1	Factor 2	Indicator	Weight
Global Economic Condition	Exchange rate	KRW/USD	0.075
	Global Supply Chain	Baltic dry index	0.033
		Global supply chain pressure	0.024
	Commodity	Crude oil price	0.021
		Bloomberg Commodity Index	0.018
		Gold price	0.004
	U.S. Economic condition	U.S. Industrial Production Index	0.009
		U.S. money stock M1	0.004
		U.S. money stock M2	0.006
		U.S standard interest rate	0.008
		U.S. economic policy uncertainty	0.009
		Dow Jones Index	0.011
	Main exporter and importer	Export/import to U.S.	0.027
		Export/import to China	0.024
		Export/import to Vietnam	0.015
Domestic Economic Condition	Economic fluctuations	Leading Index	0.023
		Coincident Index	0.021
		Lagging Index	0.018
	Sentiment	Economic Sentiment Index	0.016
		Consumer Sentiment Index	0.013
	Price related	Standard interest rate	0.009
		Expected inflation rate	0.008
		Domestic supply price index	0.017
	All industry activity	Index of All Industry Production	0.051
	Trade activities	Total export	0.074
		Total import	0.022
Industry conditions	Employment	Employment	0.098
		New employment	0.082
	Industry shipments	Export	0.034
		Domestic	0.094
	Industry perception	Performance	0.093
		Forecast	0.039
		Total	1.000

Table 6 presents the descriptive statistics for normalized indicators. In this study, 124 weeks of data were collected, and the crisis index was calculated through the collected data.

4.2.3. Creating the Crisis Index

A crisis index was created using the weight and normalization values, and the results of the crisis index are shown in Table 7 and Figure 4. Table 1 shows that the crisis in the Korean oil refining industry has increased since the COVID-19 outbreak. The highest point of the crisis index was in May 2020 and the lowest point of the crisis index was in October 2018.

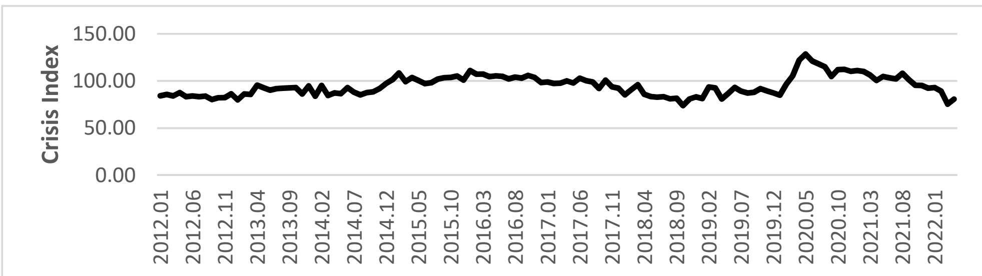


Figure 4. Crisis index for January 2012–April 2022.

Table 6. Descriptive statistics for indicators.

Indicator	Count	Mean	S.D
KRW/USD	124	100.09	4.32
Baltic dry index	124	10.53	113.82
Global supply chain pressure	124	−81.26	263.28
Crude oil price	124	57.74	51.41
Bloomberg Commodity Index	124	93.83	25.55
Gold price	124	124.75	21.67
U.S. Industrial Production Index	124	99.21	2.91
U.S. money stock M1	124	201.12	198.28
U.S. money stock M2	124	116.59	28.16
U.S standard interest rate	124	276.92	276.18
U.S. economic policy uncertainty	124	74.45	45.09
Dow Jones Index	124	125.15	37.86
Export/import to U.S.	124	104.31	12.16
Export/import to China	124	111.39	22.61
Export/import to Vietnam	124	136.49	54.80
Leading Index	124	151.97	70.60
Coincident Index	124	103.58	18.76
Lagging Index	124	120.07	26.73
Economic Sentiment Index	124	106.71	12.17
Consumer Sentiment Index	124	105.02	8.83
Standard interest rate	124	105.97	10.16
Expected inflation rate	124	99.23	6.58
Domestic supply price index	124	98.36	6.51
Index of All Industry Production	124	102.25	21.01
Total export	124	106.19	49.53
Total import	124	105.49	5.71
Employment	124	103.98	5.99
New employment	124	106.76	11.40
Export	124	116.18	16.58
Domestic	124	108.74	8.64
Performance	124	100.24	38.24
Forecast	124	104.42	10.07

4.3. Phase 3: Verifying the Crisis Index (C.I.) Using Johansen Cointegration Test

The crisis index was formulated using the limited information currently available based on historical data. Although the variables that constitute the index can impact stock prices, the crisis index derived from various techniques does not necessarily correspond with them. Stock prices are determined through a complex interplay of numerous factors, exhibiting randomness and irregularity, rendering trends statistically unpredictable. In the financial literature, stock prices are depicted as a multifaceted equation involving past information and future expectations. Statistically, stock returns in the capital market are influenced by a dynamic combination of factors that display randomness and irregularity. Factors such as market participants' behavior, economic conditions, political events, and corporate performance all contribute to stock prices and are inherently difficult to predict, exhibiting unpredictable volatility. Consequently, the presently unpredictable stock returns cannot be employed as risk information at the corporate or industrial level.

However, if the crisis index, calculated using various methodologies, shows a statistical correlation (not causality) with actual stock prices, it becomes meaningful as an indicator representing corporate risk. Therefore, the computed crisis index can serve as information reflecting a crisis at corporate or industrial levels, providing practical implications. To verify this correlation, the present study employed the Johansen cointegration test, a renowned statistical method for examining relationships between two-time series data. Specifically, the relationship between the stock return and the development index was verified using the Johansen cointegration test. It is important to note that, while the Johansen test confirms cointegration, it does not guarantee causation. Thus, the research scope in this study was limited to the correlation between the crisis index and stock prices.

Table 7. Crisis index for January 2012–April 2022.

Y/M	Crisis Index	Y/M	Crisis Index	Y/M	Crisis Index	Y/M	Crisis Index
2012.01	84.35	2014.08	85.18	2017.03	97.65	2019.10	91.80
2012.02	85.67	2014.09	87.71	2017.04	100.03	2019.11	89.48
2012.03	84.19	2014.10	88.49	2017.05	97.80	2019.12	87.34
2012.04	87.61	2014.11	91.95	2017.06	103.06	2020.01	84.89
2012.05	83.30	2014.12	97.34	2017.07	100.18	2020.02	96.59
2012.06	84.17	2015.01	101.52	2017.08	98.87	2020.03	105.33
2012.07	83.24	2015.02	108.40	2017.09	92.06	2020.04	122.08
2012.08	83.95	2015.03	99.27	2017.10	100.95	2020.05	128.53
2012.09	80.21	2015.04	103.66	2017.11	93.85	2020.06	121.24
2012.10	82.11	2015.05	100.57	2017.12	92.27	2020.07	118.18
2012.11	82.37	2015.06	97.12	2018.01	85.20	2020.08	114.95
2012.12	86.31	2015.07	98.12	2018.02	90.92	2020.09	104.79
2013.01	79.85	2015.08	102.02	2018.03	96.05	2020.10	112.04
2013.02	86.14	2015.09	103.50	2018.04	85.93	2020.11	112.33
2013.03	85.67	2015.10	103.72	2018.05	83.41	2020.12	110.26
2013.04	95.57	2015.11	105.27	2018.06	82.90	2021.01	110.97
2013.05	92.89	2015.12	100.86	2018.07	83.30	2021.02	110.14
2013.06	90.19	2016.01	111.09	2018.08	81.02	2021.03	106.16
2013.07	91.90	2016.02	107.13	2018.09	81.64	2021.04	100.60
2013.08	92.36	2016.03	107.36	2018.10	73.90	2021.05	104.75
2013.09	92.64	2016.04	104.53	2018.11	80.83	2021.06	103.35
2013.10	92.90	2016.05	105.46	2018.12	83.22	2021.07	102.13
2013.11	86.27	2016.06	104.94	2019.01	81.38	2021.08	108.21
2013.12	94.75	2016.07	102.11	2019.02	93.68	2021.09	101.30
2014.01	83.81	2016.08	104.16	2019.03	92.64	2021.10	95.36
2014.02	95.24	2016.09	102.95	2019.04	80.94	2021.11	95.21
2014.03	84.65	2016.10	105.81	2019.05	86.69	2021.12	92.29
2014.04	87.30	2016.11	103.75	2019.06	93.18	2022.01	93.00
2014.05	86.61	2016.12	98.38	2019.07	89.07	2022.02	89.21
2014.06	93.02	2017.01	98.99	2019.08	87.25	2022.03	75.39
2014.07	88.15	2017.02	97.34	2019.09	87.97	2022.04	80.78

The results of the Johansen cointegration test are presented in Table 8.

Table 8. Results of the Johansen cointegration test.

	Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic (p)
C.I.—Stock return	None *	0.249340	39.13096 (0.0000)

* Denotes the rejection of the hypothesis at the 0.05 level.

These findings shed light on the presence of a long-term correlation between stock returns and the developed crisis index, signifying that both variables share a notable connection. Although it remains uncertain whether there is a direct causal relationship between stock returns and the crisis index, the analysis demonstrates a statistically significant correlation between these two factors. As a result, the crisis index can be considered to be a reliable and valid measure, mainly because it does not provide information that is divergent from stock returns. Instead, the crisis index is in alignment with the representation of industry volatility, as evidenced by its strong, statistically significant correlation with stock returns. The extended relationship between the crisis index and stock returns further solidifies the relevance and importance of considering the crisis index in understanding market behavior and trends.

5. Discussion

This study derives a crisis index for the Korean petroleum industry. In previous studies, the index was created using limited indicators, and there was a limitation in that various situations could not be considered. In addition, only a limited number of people could check the crisis index. To derive the crisis index, the factors and indicators affecting the industry were identified from the extant literature. A questionnaire was constructed based on each factor and indicator; this questionnaire was used to survey ten experts to determine the factors and indicators having the greatest impact on the Korean oil refining industry. The expert group consisted of experts in management, the petroleum industry, and international trade. The relative importance of each indicator was calculated using ANP software. Additionally, the value of each indicator was normalized because the scale of each indicator was different. The Johansen cointegration test was used as the quantitative method. The analysis revealed a significant long-term relationship between stock returns and the developed index. Therefore, the developed index is validated.

The risk index calculated in this study and several events related to the industry were confirmed. The lowest crisis point occurred in October 2018. At that time, the unit price of exports increased because of rising international oil prices resulting from sanctions against Iran. Exports increased due to the increased global demand for petroleum products and the regular maintenance of oil refineries in Japan and China. The volume increased because of the normal operation of new facilities by domestic companies, and China, the ASEAN, and the EU imported many Korean oil refining products. Additionally, the industrial crisis index was high between August 2015 and November 2016. At that time, the demand for oil refining products decreased significantly due to the slowdown in the Chinese industry. The self-sufficiency rate of oil refining products in China and India increased significantly, which also caused this result. The crisis index continued to decrease from November 2017 to October 2018. At that time, a U.S. oil refinery facility was shut down because of a hurricane, and China implemented environmental regulations on the oil refining industry, resulting in a reflective profit due to reduced international supply.

6. Conclusions

In contrast to the indicators used in existing practices, this study selected variables to be used in the risk index by exploring the existing literature. In addition, weights were set using a scientific method, and the ANP was used to exclude subjectivity as much as possible. In addition, weights were provided so that decision makers related to the industry could utilize them, and validity was secured by comparing the derived index and stock return using the Johansen cointegration test.

Based on the process and results of this study, the academic implications are as follows: First, the extant literature was reviewed to identify factors and indicators that affect the industry. These factors were classified into global economic, domestic economic, and industrial conditions, and important indicators were selected from these factors. The factors and indicators are measures of the economic and crisis indices in other fields. Second, a survey was conducted with a group of experts to determine the weight of each indicator. We developed a crisis index using 32 indicators, and identified important indicators based on their weights. Third, the developed crisis index can be used to study the crisis indices of other industries.

In addition to the numerous academic implications, this study yields several noteworthy practical implications. Primarily, the vast majority of extant economic or crisis indices are generated on an annual basis. In contrast, we have devised a monthly crisis index to facilitate the expeditious dissemination of vital information among decision makers, a distinguishing attribute of our index compared to other indices. This feature paves the way for more nimble responses to economic fluctuations and crises in a time-sensitive manner. Secondly, by integrating a weighted methodology into the crisis index examined in this study, professionals within the industry can more effectively pinpoint potential crises utilizing an array of leading indicators. This capacity augments not only the rapid detection of impending crises but also promotes the execution of proactive measures to mitigate adverse effects and foster more vigorous economic expansion. Ultimately, this research serves to bolster the ongoing advancement of pioneering approaches and tactics in crisis management and economic resilience.

Despite these implications, this study proposes follow-up research based on the limitations of the study process. This study considers three factors affecting the petroleum industry. However, other factors may also be involved. Therefore, future studies should explore other factors. In addition, the weight of each indicator was based on the petroleum industry. Therefore, it is necessary to develop indicators that cover all industries, and indicators that can be used in other countries should be utilized. Lastly, since the crisis index was developed through this study, further research should be conducted to predict the index. By utilizing methods such as data mining to anticipate the crisis index, early responses to potential crises can be facilitated, promoting proactive measures against emerging challenges.

Author Contributions: Conceptualization, H.K.; methodology, K.P.; software, K.P.; validation, K.P., J.C. and H.K.; formal analysis, K.P.; investigation, H.K.; resources, K.P.; data curation, J.C.; writing—original draft preparation, K.P.; writing—review and editing, K.P.; visualization, K.P.; supervision, J.C.; project administration, J.C.; funding acquisition, H.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Research Program of the Korea Institute of Science and Technology Information (KISTI) (No. K-22-L03-C03-S01 and No. K-23-L03-C03-S01).

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kippenberger, T. Understanding why corporate and industrial crises occur. *Antidote* **1999**, *4*, 11–12. [CrossRef]
2. Hermann, C.F. Some issues in the study of international crisis. In *International Crises: Insights from Behavioral Research*; Free Press: New York, NY, USA, 1972; pp. 3–17.
3. Easton, G. Industrial networks: A review. In *Industrial Networks (Routledge Revivals)*; Routledge: London, UK, 2016; pp. 3–27.
4. Nayak, J.; Mishra, M.; Naik, B.; Swapnarekha, H.; Cengiz, K.; Shanmuganathan, V. An impact study of COVID-19 on six different industries: Automobile, energy and power, agriculture, education, travel and tourism and consumer electronics. *Expert Syst.* **2022**, *39*, e12677. [CrossRef] [PubMed]
5. Hsieh, W.-J. Effects of oil price shocks and macroeconomic conditions on output fluctuations for Korea. *J. Int. Glob. Econ. Stud.* **2008**, *1*, 84–91.
6. Luft, G. Energy and environmental challenges to security. In *Dependence on Middle East Energy and Its Impact on Global Security*; Springer: Berlin/Heidelberg, Germany, 2009; pp. 197–210.
7. Mhalla, M. The impact of novel coronavirus (COVID-19) on the global oil and aviation markets. *J. Asian Sci. Res.* **2020**, *10*, 96–104. [CrossRef]
8. Orencio, P.M.; Fujii, M. A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). *Int. J. Disaster Risk Reduct.* **2013**, *3*, 62–75. [CrossRef]
9. Entani, T.; Sugihara, K. Uncertainty index based interval assignment by Interval AHP. *Eur. J. Oper. Res.* **2012**, *219*, 379–385. [CrossRef]
10. Wong, W.P.; Ignatius, J.; Soh, K.L. What is the leanness level of your organisation in lean transformation implementation? An integrated lean index using ANP approach. *Prod. Plan. Control* **2014**, *25*, 273–287. [CrossRef]
11. Adebiyi, F.M. Air quality and management in petroleum refining industry: A review. *Environ. Chem. Ecotoxicol.* **2022**, *4*, 89–96. [CrossRef]
12. Park, S.; Kwon, J.; Kim, T. Developing an early warning system for the shipping industry in Korea using two approaches. *Marit. Policy Manag.* **2022**, *49*, 1–18. [CrossRef]
13. Angelopoulou, E.; Balfoussia, H.; Gibson, H.D. Building a financial conditions index for the euro area and selected euro area countries: What does it tell us about the crisis? *Econ. Model.* **2014**, *38*, 392–403. [CrossRef]
14. Kim, D.H.; Lee, S.J.; Oh, K.J.; Kim, T.Y. An early warning system for financial crisis using a stock market instability index. *Expert Syst.* **2009**, *26*, 260–273. [CrossRef]
15. Apoteker, T.; Barthélémy, S. Predicting financial crises in emerging markets using a composite non-parametric model. *Emerg. Mark. Rev.* **2005**, *6*, 363–375. [CrossRef]

16. Holm, J.R.; Østergaard, C.R. Regional employment growth, shocks and regional industrial resilience: A quantitative analysis of the Danish ICT sector. *Reg. Stud.* **2015**, *49*, 95–112. [CrossRef]
17. Boorman, J.; Fajgenbaum, J.; Ferhani, H.; Bhaskaran, M.; Arnold, D.; Kohli, H.A. The Centennial resilience index: Measuring countries' resilience to shock. *Glob. J. Emerg. Mark. Econ.* **2013**, *5*, 57–98. [CrossRef]
18. Eraydin, A. Attributes and characteristics of regional resilience: Defining and measuring the resilience of Turkish regions. *Reg. Stud.* **2016**, *50*, 600–614. [CrossRef]
19. Han, Y.; Goetz, S.J. Predicting US county economic resilience from industry input-output accounts. *Appl. Econ.* **2019**, *51*, 2019–2028. [CrossRef]
20. Di Tommaso, M.R.; Prodi, E.; Pollio, C.; Barbieri, E. Conceptualizing and measuring "industry resilience": Composite indicators for postshock industrial policy decision-making. *Socio-Econ. Plan. Sci.* **2022**, *85*, 101448. [CrossRef]
21. Färe, R.; Grosskopf, S.; Norris, M.; Zhang, Z. Productivity growth, technical progress, and efficiency change in industrialized countries. In *The American Economic Review*; American Economic Association: Nashville, TN, USA, 1994; pp. 66–83.
22. Rockart, J.F. Chief executives define their own data needs. *Harv. Bus. Rev.* **1979**, *57*, 81–93.
23. Yan, E.; Ding, Y. Applying centrality measures to impact analysis: A coauthorship network analysis. *J. Am. Soc. Inf. Sci. Technol.* **2009**, *60*, 2107–2118. [CrossRef]
24. Miller, K.; McAdam, R.; McAdam, M. A systematic literature review of university technology transfer from a quadruple helix perspective: Toward a research agenda. *R&D Manag.* **2018**, *48*, 7–24.
25. Carayannis, E.G.; Grigoroudis, E.; Campbell, D.F.; Meissner, D.; Stamati, D. The ecosystem as helix: An exploratory theory-building study of regional co-opetitive entrepreneurial ecosystems as Quadruple/Quintuple Helix Innovation Models. *R&D Manag.* **2018**, *48*, 148–162.
26. Dawes, S.S.; Gharawi, M.A.; Burke, G.B. Transnational public sector knowledge networks: Knowledge and information sharing in a multi-dimensional context. *Gov. Inf. Q.* **2012**, *29*, S112–S120. [CrossRef]
27. Saaty, T.L. Decision making—The analytic hierarchy and network processes (AHP/ANP). *J. Syst. Sci. Syst. Eng.* **2004**, *13*, 1–35. [CrossRef]
28. Saaty, T.L. The modern science of multicriteria decision making and its practical applications: The AHP/ANP approach. *Oper. Res.* **2013**, *61*, 1101–1118. [CrossRef]
29. Saaty, T.L.; Takizawa, M. Dependence and independence: From linear hierarchies to nonlinear networks. *Eur. J. Oper. Res.* **1986**, *26*, 229–237. [CrossRef]
30. Tavana, M.; Yazdani, M.; Di Caprio, D. An application of an integrated ANP–QFD framework for sustainable supplier selection. *Int. J. Logist. Res. Appl.* **2017**, *20*, 254–275. [CrossRef]
31. Saaty, T.L. Basic theory of the analytic hierarchy process: How to make a decision. *Rev. Real Acad. Cienc. Exactas Fis. Nat.* **1999**, *93*, 395–423.
32. Cao, J.; Song, W. Risk assessment of co-creating value with customers: A rough group analytic network process approach. *Expert Syst. Appl.* **2016**, *55*, 145–156. [CrossRef]
33. Huang, S.; Tang, L.; Hupy, J.P.; Wang, Y.; Shao, G. A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. *J. For. Res.* **2021**, *32*, 1–6. [CrossRef]
34. Johansen, S. Estimation and hypothesis testing of cointegration vectors in Gaussian vector autoregressive models. *Econom. J. Econom. Soc.* **1991**, *59*, 1551–1580. [CrossRef]
35. Fama, E.F. Stock returns, real activity, inflation, and money. *Am. Econ. Rev.* **1981**, *71*, 545–565.
36. Fama, E.F. Term-structure forecasts of interest rates, inflation and real returns. *J. Monet. Econ.* **1990**, *25*, 59–76. [CrossRef]
37. Pearce, D.K.; Roley, V.V. The reaction of stock prices to unanticipated changes in money: A note. *J. Financ.* **1983**, *38*, 1323–1333. [CrossRef]
38. Dwyer, G.P. The Johansen Tests for Cointegration. *White Pap.* **2015**, 1–7. Available online: http://jerrydwyer.com/pdf/Clemson/Cointegration.pdf (accessed on 20 May 2022).
39. Danmola, R.A. The impact of exchange rate volatility on the macro economic variables in Nigeria. *Eur. Sci. J.* **2013**, *9*, 152–165.
40. Bartram, S.M. Corporate cash flow and stock price exposures to foreign exchange rate risk. *J. Corp. Financ.* **2007**, *13*, 981–994. [CrossRef]
41. Golub, S.S. Oil prices and exchange rates. *Econ. J.* **1983**, *93*, 576–593. [CrossRef]
42. Ederington, L.H.; Fernando, C.S.; Hoelscher, S.A.; Lee, T.K.; Linn, S.C. A review of the evidence on the relation between crude oil prices and petroleum product prices. *J. Commod. Mark.* **2019**, *13*, 1–15. [CrossRef]
43. Scarcioffolo, A.R.; Etienne, X. Testing directional predictability between energy prices: A quantile-based analysis. *Resour. Policy* **2021**, *74*, 102258. [CrossRef]
44. Chen, Y.; Xu, J.; Miao, J. Dynamic volatility contagion across the Baltic dry index, iron ore price and crude oil price under the COVID-19: A copula-VAR-BEKK-GARCH-X approach. *Resour. Policy* **2023**, *81*, 103296. [CrossRef]
45. Zhang, X.; Chen, M.; Wang, M.; Ge, Y.; Stanley, H.E. A novel hybrid approach to Baltic Dry Index forecasting based on a combined dynamic fluctuation network and artificial intelligence method. *Appl. Math. Comput.* **2019**, *361*, 499–516. [CrossRef]
46. Giannarakis, G.; Lemonakis, C.; Sormas, A.; Georganakis, C. The effect of Baltic Dry Index, gold, oil and usa trade balance on dow jones sustainability index world. *Int. J. Econ. Financ. Issues* **2017**, *7*, 155.

47. Kalemli-Ozcan, S.; Silva, A.; Yildirim, M.A.; di Giovanni, J. *Global Supply Chain Pressures, International Trade, and Inflation*; Federal Reserve Bank of New York: New York, NY, USA, 2022.
48. Berument, M.H.; Ceylan, N.B.; Dogan, N. The impact of oil price shocks on the economic growth of selected MENA1 countries. *Energy J.* **2010**, *31*, 149–176. [CrossRef]
49. Hamilton, J.D. Oil and the macroeconomy since World War II. *J. Political Econ.* **1983**, *91*, 228–248. [CrossRef]
50. Lescaroux, F.; Mignon, V. On the influence of oil prices on economic activity and other macroeconomic and financial variables. *OPEC Energy Rev.* **2008**, *32*, 343–380. [CrossRef]
51. Ferderer, J.P. Oil price volatility and the macroeconomy. *J. Macroecon.* **1996**, *18*, 1–26. [CrossRef]
52. Loungani, P. Oil price shocks and the dispersion hypothesis. In *The Review of Economics and Statistics*; The MIT Press: Cambridge, MA, USA, 1986; pp. 536–539.
53. Gospodinov, N.; Ng, S. Commodity prices, convenience yields, and inflation. *Rev. Econ. Stat.* **2013**, *95*, 206–219. [CrossRef]
54. Garner, C.A. Commodity prices: Policy target or information variable?: Note. *J. Money Credit. Bank.* **1989**, *21*, 508–514. [CrossRef]
55. Thatcher, M.E.; Oliver, J.R. The impact of technology investments on a firm's production efficiency, product quality, and productivity. *J. Manag. Inf. Syst.* **2001**, *18*, 17–45. [CrossRef]
56. Wang, Y.; Liu, L.; Wu, C. Forecasting commodity prices out-of-sample: Can technical indicators help? *Int. J. Forecast.* **2020**, *36*, 666–683. [CrossRef]
57. James, H. International cooperation and central banks. In *The Oxford Handbook of Banking and Financial History*; Oxford University Press: Oxford, UK, 2016.
58. Choi, C. Subordinate financialization and financial subsumption in South Korea. *Reg. Stud.* **2020**, *54*, 209–218. [CrossRef]
59. Arize, A.C.; Malindretos, J. Foreign exchange reserves in Asia and its impact on import demand. *Int. J. Econ. Financ.* **2012**, *4*, 21–32. [CrossRef]
60. Sugiharti, L.; Esquivias, M.A.; Setyorani, B. The impact of exchange rate volatility on Indonesia's top exports to the five main export markets. *Heliyon* **2020**, *6*, e03141. [CrossRef]
61. Li, M.; Balistreri, E.J.; Zhang, W. The US–China trade war: Tariff data and general equilibrium analysis. *J. Asian Econ.* **2020**, *69*, 101216. [CrossRef]
62. McCracken, M.W.; Ng, S. FRED-MD: A monthly database for macroeconomic research. *J. Bus. Econ. Stat.* **2016**, *34*, 574–589. [CrossRef]
63. Pascal, V.; Toufik, A.; Manuel, A.; Florent, D.; Frédéric, K. Improvement indicators for total productive maintenance policy. *Control Eng. Pract.* **2019**, *82*, 86–96. [CrossRef]
64. Summers, L.H. US economic prospects: Secular stagnation, hysteresis, and the zero lower bound. *Bus. Econ.* **2014**, *49*, 65–73. [CrossRef]
65. Bjørnland, H.C.; Leitemo, K. Identifying the interdependence between US monetary policy and the stock market. *J. Monet. Econ.* **2009**, *56*, 275–282. [CrossRef]
66. McCauley, D.J.; Pinsky, M.L.; Palumbi, S.R.; Estes, J.A.; Joyce, F.H.; Warner, R.R. Marine defaunation: Animal loss in the global ocean. *Science* **2015**, *347*, 1255641. [CrossRef]
67. Colombo, V. Economic policy uncertainty in the US: Does it matter for the Euro area? *Econ. Lett.* **2013**, *121*, 39–42. [CrossRef]
68. Pergams, O.R.; Czech, B.; Haney, J.C.; Nyberg, D. Linkage of conservation activity to trends in the US economy. *Conserv. Biol.* **2004**, *18*, 1617–1623. [CrossRef]
69. Sharif, A.; Aloui, C.; Yarovaya, L. COVID-19 pandemic, oil prices, stock market, geopolitical risk and policy uncertainty nexus in the US economy: Fresh evidence from the wavelet-based approach. *Int. Rev. Financ. Anal.* **2020**, *70*, 101496. [CrossRef]
70. Milani, F.; Park, S.H. The effects of globalization on macroeconomic dynamics in a trade-dependent economy: The case of Korea. *Econ. Model.* **2015**, *48*, 292–305. [CrossRef]
71. Zang, W.; Baimbridge, M. Exports, imports and economic growth in South Korea and Japan: A tale of two economies. *Appl. Econ.* **2012**, *44*, 361–372. [CrossRef]
72. Fosu, A.K. Exports and economic growth: The African case. *World Dev.* **1990**, *18*, 831–835. [CrossRef]
73. Mahadevan, R.; Nugroho, A. Can the Regional Comprehensive Economic Partnership minimise the harm from the United States–China trade war? *World Econ.* **2019**, *42*, 3148–3167. [CrossRef]
74. Huong, T.T.; Shah, I.H. Dynamics of economy-wide resource flow and consumption in China, South Korea, and Vietnam—A pan-regional analysis. *Environ. Monit. Assess.* **2021**, *193*, 585. [CrossRef]
75. Freeman, A.; Tyrovolas, S.; Koyanagi, A.; Chatterji, S.; Leonardi, M.; Ayuso-Mateos, J.L.; Tobiasz-Adamczyk, B.; Koskinen, S.; Rummel-Kluge, C.; Haro, J.M. The role of socio-economic status in depression: Results from the COURAGE (aging survey in Europe). *BMC Public Health* **2016**, *16*, 1098. [CrossRef]
76. Lee, C.; Park, J. The Time-Varying Effect of Interest Rates on Housing Prices. *Land* **2022**, *11*, 2296. [CrossRef]
77. Heshmati, A.; Oh, J. Alternative Composite Lisbon Development Strategy Indices: A Comparison of EU, USA, Japan and Korea. *Eur. J. Comp. Econ.* **2006**, *3*, 133–170.
78. Moon, H.-J. Construction of an economic sentiment indicator for the Korean economy. *Korean J. Appl. Stat.* **2011**, *24*, 745–758. [CrossRef]
79. Song, M.; Shin, K.s. Forecasting economic indicators using a consumer sentiment index: Survey-based versus text-based data. *J. Forecast.* **2019**, *38*, 504–518. [CrossRef]

80. Acemoglu, D.; Scott, A. Consumer confidence and rational expectations: Are agents' beliefs consistent with the theory? *Econ. J.* **1994**, *104*, 1–19. [CrossRef]
81. Howrey, E.P. The predictive power of the index of consumer sentiment. *Brook. Pap. Econ. Act.* **2001**, *2001*, 175–207. [CrossRef]
82. Hadood, A.A.A.; Irani, F. Impact of economic sentiment and economic policy uncertainty on travel and leisure stock return. *J. Hosp. Tour. Insights* **2020**, *4*, 98–120. [CrossRef]
83. Andersson, F.N. Monetary policy, asset price inflation and consumer price inflation. *Econ. Bull.* **2011**, *31*, 759–770.
84. Blinder, A.S.; Triplett, J.E.; Denison, E.; Pechman, J. The consumer price index and the measurement of recent inflation. *Brook. Pap. Econ. Act.* **1980**, *1980*, 539–573. [CrossRef]
85. Dougherty, A.; Van Order, R. Inflation, housing costs, and the consumer price index. *Am. Econ. Rev.* **1982**, *72*, 154–164.
86. Jonung, L. Perceived and expected rates of inflation in Sweden. *Am. Econ. Rev.* **1981**, *71*, 961–968.
87. Akcay, S. The causal relationship between producer price index and consumer price index: Empirical evidence from selected European countries. *Int. J. Econ. Financ.* **2011**, *3*, 227–232. [CrossRef]
88. Tiwari, A.K. An empirical investigation of causality between producers' price and consumers' price indices in Australia in frequency domain. *Econ. Model.* **2012**, *29*, 1571–1578. [CrossRef]
89. Loupias, C.; Sevestre, P. Costs, demand, and producer price changes. *Rev. Econ. Stat.* **2013**, *95*, 315–327. [CrossRef]
90. Hyde, S. The response of industry stock returns to market, exchange rate and interest rate risks. *Manag. Financ.* **2007**, *33*, 693–709. [CrossRef]
91. Yeo, H.-J. Role of free cash flows in making investment and dividend decisions: The case of the shipping industry. *Asian J. Shipp. Logist.* **2018**, *34*, 113–118. [CrossRef]
92. Ang, A.; Bekaert, G.; Wei, M. The term structure of real rates and expected inflation. *J. Financ.* **2008**, *63*, 797–849. [CrossRef]
93. Rahman, M.M.; Mamun, S.A.K. Energy use, international trade and economic growth nexus in Australia: New evidence from an extended growth model. *Renew. Sustain. Energy Rev.* **2016**, *64*, 806–816. [CrossRef]
94. Wacziarg, R. Measuring the dynamic gains from trade. *World Bank Econ. Rev.* **2001**, *15*, 393–429. [CrossRef]
95. Pierce, J.R.; Schott, P.K. The surprisingly swift decline of US manufacturing employment. *Am. Econ. Rev.* **2016**, *106*, 1632–1662. [CrossRef]
96. Dainty, A.R.; Edwards, D.J. The UK building education recruitment crisis: A call for action. *Constr. Manag. Econ.* **2003**, *21*, 767–775. [CrossRef]
97. Streeck, J.; Pauliuk, S.; Wieland, H.; Wiedenhofer, D. A review of methods to trace material flows into final products in dynamic material flow analysis: From industry shipments in physical units to monetary input–output tables, Part 1. *J. Ind. Ecol.* **2023**, *27*, 436–456. [CrossRef]
98. Marvel, H.P.; Ray, E.J. Intraindustry trade: Sources and effects on protection. *J. Political Econ.* **1987**, *95*, 1278–1291. [CrossRef]
99. Lehmann, R. The forecasting power of the ifo business survey. *J. Bus. Cycle Res.* **2022**, *19*, 43–94. [CrossRef]
100. Aydin, U. Promoting industries in the global economy: Subsidies in OECD countries, 1989 to 1995. *J. Eur. Public Policy* **2007**, *14*, 115–131. [CrossRef]
101. Dong, F.; Hu, M.; Gao, Y.; Liu, Y.; Zhu, J.; Pan, Y. How does digital economy affect carbon emissions? Evidence from global 60 countries. *Sci. Total Environ.* **2022**, *852*, 158401. [CrossRef] [PubMed]
102. Sun, S. How does FDI affect domestic firms' exports? Industrial evidence. *World Econ.* **2009**, *32*, 1203–1222. [CrossRef]
103. You, K.; Solomon, O.H. China's outward foreign direct investment and domestic investment: An industrial level analysis. *China Econ. Rev.* **2015**, *34*, 249–260. [CrossRef]
104. MacKay, P.; Phillips, G.M. How does industry affect firm financial structure? *Rev. Financ. Stud.* **2005**, *18*, 1433–1466. [CrossRef]
105. Porter, M.E. The structure within industries and companies' performance. In *The Review of Economics and Statistics*; The MIT Press: Cambridge, MA, USA, 1979; pp. 214–227.
106. Maurer, A.; Degain, C. Globalization and trade flows: What you see is not what you get! *J. Int. Commer. Econ. Policy* **2012**, *3*, 1250019. [CrossRef]
107. Arouri, M.E.H. Does crude oil move stock markets in Europe? A sector investigation. *Econ. Model.* **2011**, *28*, 1716–1725. [CrossRef]
108. Joo, K.; Suh, J.H.; Lee, D.; Ahn, K. Impact of the global financial crisis on the crude oil market. *Energy Strategy Rev.* **2020**, *30*, 100516. [CrossRef]
109. Adrangi, B.; Chatrath, A.; Raffiee, K. Economic activity, inflation, and hedging: The case of gold and silver investments. *J. Wealth Manag.* **2003**, *6*, 60–77. [CrossRef]
110. Riezman, R.G.; Whiteman, C.H.; Summers, P.M. *The Engine of Growth or Its Handmaiden? A Time-Series Assessment of Export-Led Growth*; Springer: Berlin/Heidelberg, Germany, 1996.
111. Timmer, M.P.; Inklaar, R.; O'Mahony, M.; Van Ark, B. Productivity and economic growth in Europe: A comparative industry perspective. *Int. Product. Monit.* **2011**, *21*, 3.
112. Hartwell, R.M. *The Industrial Revolution and Economic Growth*; Routledge: London, UK, 2017.
113. Mishkin, F.S. The information in the longer maturity term structure about future inflation. *Q. J. Econ.* **1990**, *105*, 815–828. [CrossRef]
114. Laidler, D.; Parkin, M. Inflation: A survey. *Econ. J.* **1975**, *85*, 741–809. [CrossRef]

115. Wei, K.J.; Wong, K.M. Tests of inflation and industry portfolio stock returns. *J. Econ. Bus.* **1992**, *44*, 77–94. [CrossRef]
116. Okstad, E.; Jersin, E.; Tinmannsvik, R.K. Accident investigation in the Norwegian petroleum industry–Common features and future challenges. *Saf. Sci.* **2012**, *50*, 1408–1414. [CrossRef]

MDPI
St. Alban-Anlage 66
4052 Basel
Switzerland
www.mdpi.com

Energies Editorial Office
E-mail: energies@mdpi.com
www.mdpi.com/journal/energies

Academic Open
Access Publishing

mdpi.com

ISBN 978-3-0365-9605-1