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The Effect of COVID-19 Pandemic on the Energy Economics and Markets in Central and Eastern Europe

Edited by
Jakub Kraciuk and Elzbieta Kacperska

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About the Editors

Jakub Kraciuk

Jakub Kraciuk is a professor at the Warsaw University of Life Sciences, employed at the Institute of Economics and Finance of this university. His research interests focus on international economics, with particular emphasis on economic globalization and its effects, such as concentration processes in the world economy as well as processes of fragmentation and delocalization of production. In his scientific work, he also dealt with the activities of transnational corporations, financial crises and their impact on the global economy and the economies of individual countries, as well as the flow of goods for services and production factors on an international scale. Recently, his research has focused on the analysis and comparison of the use of renewable energy sources (RESs) in the countries of the European Union and the Visegrad Group. This research aims to assess the effectiveness of implementing innovative energy technologies and sustainable development strategies on energy markets in various regions of Europe. He is also the supervisor of four doctoral theses and many bachelor's and master's theses in the field of economics and finance. Moreover, he is a member of the Editorial Board of the SGGW scientific journal *Problems of World Agriculture*. He was vice dean for science and dean of the Faculty of Economics at SGGW. He also served as a coordinator of research on representatives of the rural elite in Poland, carried out under the sixth framework program of the European Union, implemented by the Institute of Agricultural Economics of the University of Kie.

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Preface

This reprint provides a comprehensive study of the impact of the COVID-19 pandemic on energy markets in Central and Eastern Europe. The COVID-19 pandemic has introduced significant changes and challenges to the energy sector worldwide. Sudden changes in energy demand, the need to adapt to new market and political conditions, and the increasing role of sustainable development and renewable energy sources have compelled the energy sector to seek innovative solutions. The motivation for writing this reprint was to understand these dynamic changes and their long-term consequences for the energy sector, economy, and society.

The goal of this publication is to understand and analyze the impact of the COVID-19 pandemic on various aspects of the energy sector in Central and Eastern Europe, with a particular focus on Poland. The analysis covers several key aspects, such as innovative energy technologies in road transport in selected EU countries, changes in energy consumption, implementation of renewable energy technologies, CSR policies, employment in the energy sector, and risks associated with the pandemic.

This publication is addressed to a broad audience, including researchers, students, policymakers, energy sector workers, and anyone interested in renewable energy and its role in sustainable development. This reprint aims to provide valuable information and analyses that can support decision-making, policy formulation, and the development of innovative energy technologies.

This reprint is the result of in-depth research and analyses aimed at shedding new light on the dynamically changing landscape of the energy sector in the face of the COVID-19 pandemic. I warmly invite you to read and reflect on the issues presented herein.

Jakub Kraciuk and Elzbieta Kacperska
Editors

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Article

Innovative Energy Technologies in Road Transport in Selected EU Countries

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Abstract: The primary aim of this study was to assess and classify selected EU countries to groups differing in terms of the degree of implementation of innovative energy technologies to alleviate adverse externalities in road transport. This aim was realised using three groups of research methods: collection of empirical data, data processing and presentation of study outcomes. When collecting the research material, the authors used the method of critical literature review and the documentation method. The research material was processed using the agglomerative clustering technique, which was one of the hierarchical clustering methods. The distance between objects (here, selected EU countries) was determined based on the Euclidean distance. The outcome of this analysis was a dendrogram, which constitutes a graphical interpretation of obtained results. The study was conducted on 21 EU countries. The analyses covered the years 2013–2019. The sources of materials included literature on the subject and the Eurostat data. The problem of innovative energy technologies in road transport is presently of considerable importance. This results from the current situation related to human activity. As a result of the conducted cluster analysis, groups were distinguished based on differences in the use of innovative energy technologies alleviating negative externalities generated by road transport. The first group comprised Sweden, the Netherlands and Finland. Compared to the other groups, this group was distinguished by the highest values of four indexes, i.e., the share of renewable energy sources used in transport in 2019, the share in the market of electric passenger vehicles in 2019, the share in the market of electric lorries in 2019, as well as the share in the market of hybrid automobiles in 2019. Countries which participated the least in the elimination of negative externalities generated by road transport included Romania, Hungary, Greece, Poland, Latvia and Estonia.

Keywords: road transport; externalities of transport; innovative energy technologies; renewable energy sources; the European Union

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1. Introduction

Innovations in the energy sector are necessary for a variety of reasons, including climate change, increasing the availability of safe and affordable energy and the growing use of renewable energy sources. Transport is a unique sector of the economy, contributing to socio-economic development, but also generating external costs. The increasing number of vehicles used in road transport in the EU, depletion of fossil fuel resources and environmental concerns have all contributed to the search for alternative solutions to be implemented as innovative energy technologies in road transport. This type of transport in the European Union countries is one of the most dynamically developing sectors of the economy and, as a result, is also the one with the greatest environmental impact.

The problem of innovative energy technologies in road transport has been investigated by numerous researchers. These analyses typically concerned the use of renewable energy sources in road transport [1–5], implementation of innovative energy technologies by selected countries [6,7], various directions of development of innovative energy technologies, e.g., use of electric vehicles [8,9], hydrogen vehicles [10,11] and connected and autonomous vehicles [12,13]. Very few publications are available in the literature on the subject concerning comparisons of this problem at the international scale.

The aim of this paper is to assess and classify selected EU countries into groups differing in terms of the use of innovative energy technologies to alleviate negative externalities in road transport. In order to realise this aim, a set of the following research tasks was established: (1) to conduct a review of Polish and foreign literature concerning innovative energy technologies limiting negative externalities in road transport, (2) to present changes in the use of renewable energy sources in road transport in the EU countries in the years 2013–2019; (3) to identify leaders among the EU countries in the use of innovative energy technologies in road transport.

The authors also undertook verification of the following research hypothesis:

Hypothesis 1 (H1). *Only a few EU member countries can be described as leaders in the use of innovative energy technologies in road transport.*

This paper is composed of five parts. The first chapter, constituting the Introduction, presents a justification for the selection of the study subject, the main aim and research tasks. The next chapter gives information on the material and adopted research methods. The third part provides a review of literature on innovative energy technologies alleviating negative externalities in road transport. The fourth part presents the results of conducted analyses, along with the discussion concerning results reported by other authors. The final part of the paper comprises concluding remarks together with the presentation of limitations of this study, while also suggesting proposals for further directions of research on the subject.

2. Literature Review

Innovations are a concept that was introduced for the first time in economic sciences by J.A. Schumpeter in 1912. He distinguished [14]:

- Manufacturing novel products or improvement of existing products;
- Use of new production methods;
- Opening of a new sales market;
- Development of a novel type of product;
- Acquisition of new sources of raw materials or intermediate goods;
- Creation of a new branch organisation.

In the approach proposed by that author, we deal with technological, organisational and economic changes in the phenomenon of entrepreneurship, as indicated by both the process and the innovative character of these actions [15]. Innovations were also discussed by [16–18]. The best known and most commonly used definition of innovation is that published in the Oslo Manual in 2005 [19,20], in which innovations are defined as introducing new or considerably improved products on the market or finding better ways to launch new products on the market. Innovation is related to innovativeness [21]. Innovative activity is a process of developing innovations through scientific, technological, organisational, financial and marketing activities. Some of those mentioned above are innovative by themselves, or they are not novelties, but they constitute an indispensable element for the implementation of an innovation. For innovations to be feasible, research and development activity is required [22].

Both technological and systemic innovations play a considerable role in the process of energy transition. Priorities need to be innovations in the use of transport, industry and the construction sectors. Particular attention should be focused on the application of advanced technologies in energy storage, smart charging systems for electric vehicles, or establishment of small, local grids. Innovations in the energy sector are necessary in view of climate change, increased availability of safe and affordable energy, as well as the growing use of renewable energy sources (. . .) [23]. Innovative energy technologies in the transport sector are related to increased energy efficiency provided by advanced technical solutions consisting of the use of alternative fuels. At present, the focus is on the implementation of zero-emission solutions in transport, i.e., the use of electric energy and hydrogen to power vehicles [24]. Similar solutions are used, e.g., in China (development of electric vehicle (EV) technology [25]. The discussed problem is of paramount importance and of topical interest [26]. It has been presented by numerous authors [27,28].

Transport plays a highly important and ever-increasing role in many aspects of functioning of contemporary societies, as it facilitates transport of humans and goods within countries and regions, as well as between them [29]. Transport is developed mainly thanks to the growing domestic and international trade. In turn, passenger transport is connected primarily by commuting and business trips, as well as domestic and international tourism. Within the last several decades, people have spent on average from 1 to 1.5 h daily commuting or travelling [30]. However, increasing income levels and growing accessibility of passenger transport at higher speeds, along with its increasing affordability, have all contributed to the development of societies in which people travel on business and for pleasure over ever-growing distances. The development of passenger transport related to business activity and transport of goods has been considerably facilitated by processes of economic globalisation. Obviously, the impact of these processes on transport is multifaceted. The limiting factor for passenger transport connected with commuting is connected to the increasingly common online work. This phenomenon was markedly intensified during the COVID-19 pandemic. Additionally, events termed black swans and grey rhinos also exert a considerably impact on globalisation processes, contributing to economic slowdown and limiting trade, thus reducing the scale of transport, particularly transport of goods.

In the EU in 2018, transport accounted for approx. 6.3% of gross domestic product (*GDP*), employing almost 13 million people whilst also acting as the main source of income in several EU member countries [31]. In 2019, the EU road systems were used by 242 million passenger cars (which corresponds to more than one automobile per every two people). The car ownership index was highest in Luxembourg (681 cars per 1000 inhabitants), followed by Italy, Cyprus, Finland and Poland (all with over 600), while in Hungary it was fewer than 400 per 1000 inhabitants (390), similar to Latvia (381) and Romania (357) [32].

Land transport in the EU (excluding pipelines) in 2019 is estimated at approx. 2300 billion tonnes/kilometres. A vast proportion of this number (76.3%) was connected with road transport, with railways at 17.6% and inland waterways accounting for 6.1%. Rail transport accounted for most inland transport of goods in Latvia and Lithuania (73.6% and 67.4%, respectively), while inland waterways accounted for 42.7% freight in the Netherlands [32]. The outbreak of the COVID-19 pandemic contributed to a marked decline in road transport. This was particularly evident in the case of public transport, which dropped by as much as 80–90% in major European cities in the middle of 2021 [33]. Nevertheless, in the long-term perspective, transport—including road transport, will continue to develop and its volume will increase.

Although mobility provides a variety of advantages for its users, it is also connected to social costs. T. Kamińska [34] indicated the social benefits and costs of transport (Figure 1).

According to the OECD, the effects of transport may be divided into [35]:

(1) Benefits for users:
- Changes in the duration of travel;
- Change in the maintenance costs of vehicles;
- Effect on traffic safety.

(2) Effects of transport networks:
- Creation of new traffic options;
- Intrasector shifts in demand;
- Improved reliability of transport;
- Quality of transport services.

(3) Socio-economic effects:
- Changes in availability;
- Changes in employment within the region;
- Changes in efficiency and production;
- Changes in social integration;
- Changes in property value.

(4) Environmental effects.

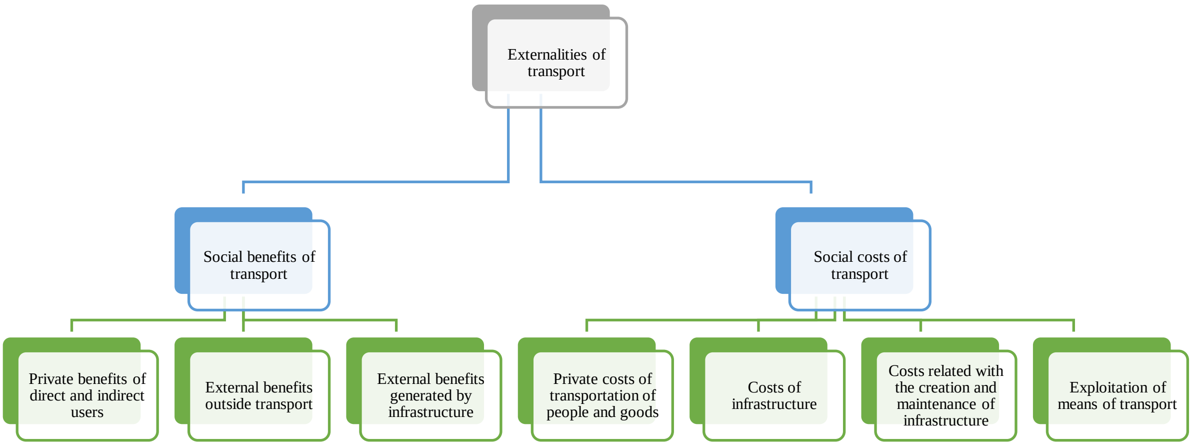

Figure 1. Externalities of transport according to T. Kamińska. Source: own study based on [34].

In terms of sustainable development for the economy, costs incurred by society in relation to provision of transport costs are essential. They are termed social costs, and are divided into two categories: internal and external (Figure 3). Internal costs result from transport activity and are incurred by the users who generate them. Costs are also incurred by society, i.e., time losses; health problems resulting from air pollution or noise; and carbon dioxide emissions, which lead to climate change [36]. They are defined as externalities or negative external effects. In terms of sustainable development, costs incurred by society in relation to transport services, defined as externalities or negative externalities, are crucial for the economy. This problem has been widely discussed in economic literature [37–41]. According to W. Rothengatter, externalities include, among other things, "involuntary interactions between entities jointly using a given resource, to which ownership right has not been established" [35,41], while E. Mishan clarified that they are generated unconsciously and constitute unintentional or accidental by-products of purposeful activity [35,42]. J. Poliński indicated that they are "all costs related to the execution of a transport service, which are not incurred by the provider of this service, or by the purchaser, but by a third party, here it is the society" [43,44]. Literature on the subject presents many divisions of external costs of road transport. Most typically, they are divided into four categories (Figure 2).

The greatest share in external costs of transport comprises environmental costs, which make up approx. 58%. They include costs related to the elimination of air pollution, changes in the natural environment and landscape, climate change associated with CO_2 emission, costs related to alleviation of environmental damage, and costs of actions aiming to reduce noise. The second item comprises costs related to accidents, which make up 29% of costs. These are costs not covered by insurance premiums, e.g., material losses, medical costs, administrative costs, etc. The share of infrastructure costs accounts for 12%, while that of congestion is 1% (Figure 3).

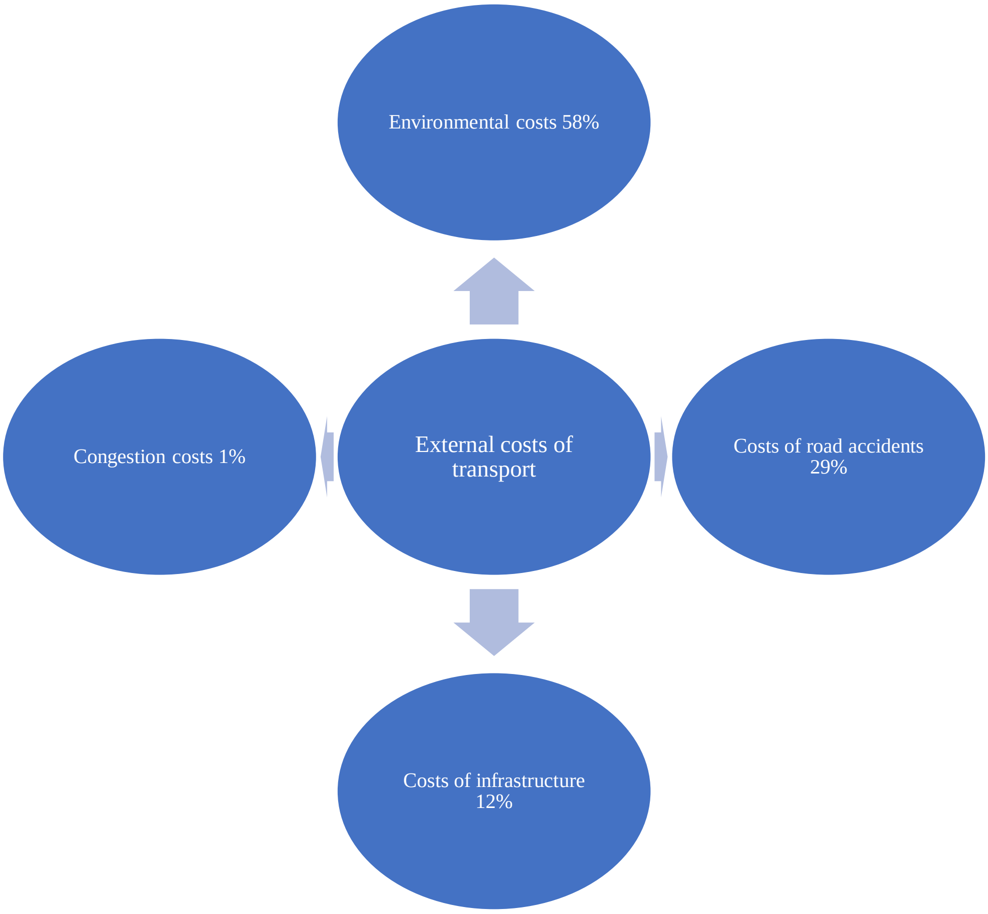

Figure 2. Categories of external costs of road transport. Source: own study based on [45].

The latter include greenhouse gas emissions, air and water pollution, as well as noise. Road transport, next to heating, is the primary factor responsible for the low air quality in European cities, and it ranks second as the source of greenhouse gases in Europe. In view of the above, it is obvious that reaching sustainable social development goals requires addressing the challenges related with the transport system as a whole, particularly road transport [46]. Many researchers point to the need to rationalize the energy consumption of road transport towards sustainable development [47,48]. For many years, the European Union has undertaken actions for sustainable development in the energy sector. This sector has been the most important issue since the beginning of integration processes in Europe [49]. In the following years, the European Union initiated works on the establishment of the single energy market, identifying priorities for this policy [50,51]. The EU defined goals related to climate and energy, within which the member countries declared that they would reduce greenhouse gas emissions by 2030, increase the share of renewable energy sources, and improve energy efficiency and the potential to transfer electricity generated within the EU to the other EU countries using the system of interconnections [52]. The recently announced EU Green Deal assumes that the EU countries are to become zero emitters, i.e., climate neutral, by 2050 [53]. In the Strategy for Sustainable and Smart Mobility—European transport on the road to the future, announced in 2020 [54], it was shown that environmentally friendly mobility has to become a new licence for the development of the transport sector. This Strategy indicates that a 90% reduction in emissions from the transport sector by 2050 is the primary goal. EU countries have to implement comprehensive transformation towards a sustainable and smart future: (1) make all types of transport more sustainable, (2) ensure extensive availability of sustainable alternative solutions in the system of multimodal transport, and

(3) implement adequate incentives promoting such a transformation [53]. The following were indicated as intermediate goals:

(1) By 2030:
- A minimum of 30 million zero-emission vehicles will be introduced onto European roads;
- 100 European cities will be climate neutral;
- High-speed rail transport will increase twofold;
- Regular public transport up to 500 km should be CO_2 emission neutral within the EU;
- Extensive implementation of automated mobility;
- Preparation for zero-emission ships to be on the market.

(2) By 2035:
- Preparation for launching of zero-emission large aircraft onto the market.

(3) By 2050:
- Almost all passenger vehicles, transport vehicles, buses and new heavy-duty lorries will be zero emission;
- Rail freight will increase twofold;
- Traffic of high-speed trains will increase threefold;
- Multimodal Trans-European Transport Network (TEN-T) will be equipped for sustainable and smart transport, ensuring fast connections.

It will operate within the comprehensive network.

The goals established for the EU transport sector are challenging. A reduction in greenhouse gas emissions by the European transport may be attained by:

(1) Limiting the energy demand of transport, e.g., modal shifts (individual private transport towards public transport, air transport towards high-speed rail, road transport towards waterway transport), through remote work, changes in prices, operational improvements or other solutions related to demand.
(2) Improvement of efficiency through electrification, hybrid systems and upgraded engines.
(3) Transition to energy carriers with lower carbon dioxide emissions, such as renewable energy or sustainable biofuels, e.g., bioethanol, biodiesel, biomethane, hydrogenated vegetable oil (HVO) and fatty acid methyl esters (FAME) [55].

As a result, decision makers face challenges requiring them to pressure this sector to reduce its externalities, while simultaneously maintaining the economic model it helps to support [56]. In this context, it is clear that top-level strategic actions aiming to regulate road transport typically promote implementation of innovative technological solutions, which may contribute to attaining both these aims. Digital solutions based on connectivity and automation of vehicles, as well as the paradigm of the sharing economy together with the transition to low-emission vehicle technologies (particularly electric vehicle and hydrogen vehicle technologies) are central elements of the European vision of smart and more eco-friendly transport [57]. Innovativeness in transport is related with the search for methods to more efficiently utilise financial, management and organisational resources. This is a particularly important problem in view of the growing transport needs and limited resources. According to forecasts in Poland and the European Union, in the near future, innovativeness in transport should focus on the following problems [58]:

- Transport methods and technologies;
- Planning, organisation and management of transport systems;
- Financing of transport in relation both to the maintenance and modernisation of existing resources, as well as new infrastructure, vehicle fleets and other resources.

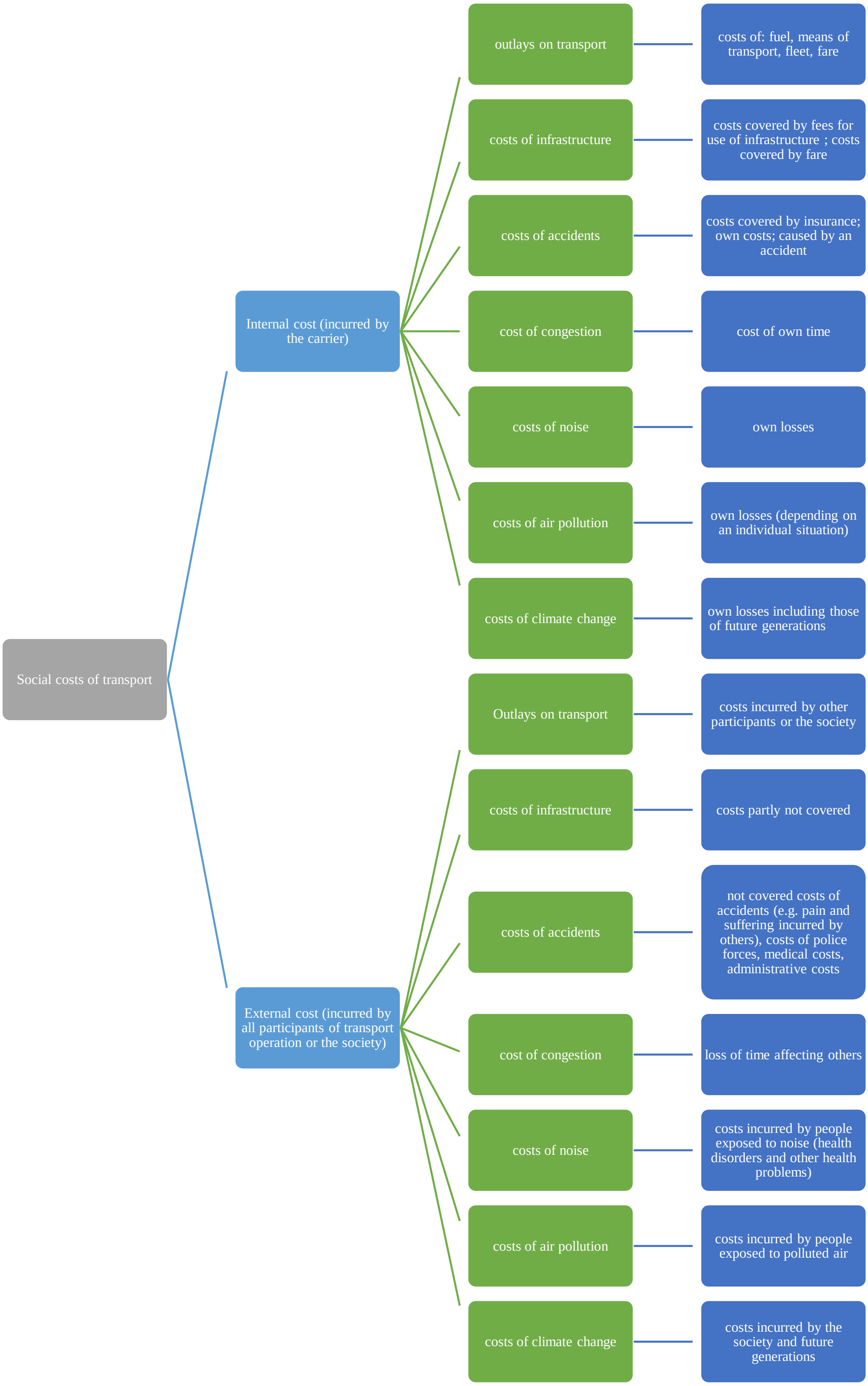

Figure 3. Classification of transport costs. Source: own study based on [36].

One of the innovation priorities in road transport may include development of battery electric vehicles (BEV) [59], which are becoming increasingly important, particularly in the privately owned automobile market. A battery electric vehicle (BEV) is an electric vehicle (EV), which is powered solely by the energy stored in batteries, with no other source (e.g., hydrogen, an internal combustion engine, etc.). Vehicles of the BEV type use an engine and an electric system instead of the internal combustion engine (ICE). These vehicles collect all the power from batteries and use it to power their engines, which additionally aids in powering their wheels [60]. A significant component of costs in these vehicles is generated by batteries. Innovative designs for batteries on the one hand aim at reducing the adverse environmental impact, especially at the stage of their production and decommissioning, while on the other hand, innovative solutions focus on increasing the energy density and power of batteries, particularly in vehicles of medium and large load-carrying capacity. In the near future, this may be reached thanks to upgrades in existing lithium-ion technologies. Over a longer time, prospective new chemical technologies may replace lithium-ion batteries, ensuring further reduction of costs and improvement of their efficiency [61].

An important role in the decarbonisation of the lorry segment may be played by flexible-fuel vehicles (FFV). In view of doubts related to the possible zero-emission technologies for lorries of large load-carrying capacity, it is crucial to develop options for combustion engines. Key innovations in this respect are related to improved fuel savings and reduction in harmful emissions. A limited hybrid type (e.g., the 48 V system, regenerative braking, also called recuperation) is particularly effective at reducing both high emissions and fuel consumption in vehicles equipped with combustion engines, which frequently stop and start to move again [61]. At present, various types of dual-fuel vehicles are produced. Among them, we may distinguish, e.g., vehicles using petrol and LPG, hydrogen and petrol or petrol and diesel oil. Dual-fuel vehicles are low-cost burdens for the development of the hydrogen infrastructure prior to the introduction of fuel-cell-powered vehicles. They are considered to be a transition stage for vehicles powered with these cells, since they use the same fuel storage systems, safety systems, valves, safety system controls, etc. Moreover, this technology may be replicated on various engine platforms while incurring relative low costs [62].

Novel engine architecture designs may bring about a greater increase in performance and efficiency parameters, although they are presently in their preliminary stages. Moreover, further integration of components is required in exhaust after-treatment systems to improve both their energy efficiency and effective removal of pollutant emissions.

In the near future, a particularly important role may be played by electric vehicles equipped with fuel cells. Vehicles with fuel cells powered by pure hydrogen are zero-emission vehicles, as in reality, the only local emission is water vapour. However, in this case, it is important to consider the complete fuel cycle, i.e., emissions related to the production, transport and supply of fuel. The basic primary source for the production of hydrogen is crucial for vehicles to be considered environmentally friendly. Hydrogen produced from renewable energy (e.g., wind or solar energy combined with electrolysis) and used in fuel cells may considerably reduce emissions. The latest studies concerning alternative fuels indicate that vehicles powered with fuel cells using hydrogen are the most promising technology in terms of reducing pollutant emissions in the fuel cycle [63]. Fuel cells are considered increasingly promising, particularly as a solution limiting pollutant emissions by lorries. They offer a similar range of distance covered as conventional diesel engine vehicles; however, the high costs of its implementation are the main drawback of such a solution. For this reason, it is also necessary to implement innovations aiming at decreasing costs of fuel cells and the hydrogen tank, since these elements are, to a considerable degree, responsible for the total cost of fuel-cell-powered vehicles. These costs may be decreased by developing large-scale production, applying greater automation. In turn, fuel cells may play an increasingly important role in the decarbonisation of vehicles of medium and large load-carrying capacity, considering the relatively high ratio of generated energy to the mass of hydrogen in comparison to batteries. This aspect was also discussed by [64,65]. It was stated that Poland has huge potential for the use of hydrogen as an alternative to conventional fuels used in the transport sector [66]. This innovative application in transport has been described by many authors [67].

A considerable challenge which may possibly change the entire infrastructure of land transport and travel is related to innovations leading to introduction of connected and autonomous vehicles. New vehicle technologies in this respect promise solutions in which sensors and specialist software will replace people as drivers [68]. A priority in the development of CAV vehicles is to create safety foundations based on this technology. Innovative technologies, validation and testing procedures are crucial for the establishment of safety standards and lowering of implementation costs for this technology [63]. Connected Autonomous Vehicles, i.e., those which are both combined and autonomous, are a technologically powerful area of potential great importance in the future, which has been shown in the publications of many authors [69–72].

3. Material and Methods

Objects for this study were selected based on purposive sampling. They are countries of the European Union (EU), for which necessary data were available, i.e., Austria (AT), Belgium (BE), Czechia (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (GE), Greece (GR), Hungary (HU), Ireland (IE), Italy (IT), Latvia (LV), the Netherlands (NL), Poland (PL), Portugal (PT), Romania (RO), Slovakia (SK), Slovenia (SI), Spain (SE) and Sweden (SW). Thus, the population sample consisted of 21 out of the 27 EU member countries. For the remaining six, the relevant variables (x_1, x_2, x_3, x_4, x_5, x_6, x_7) were not available. These variables will be described later in this section.

When selecting diagnostic variables, the authors used their experience gained in the course of previous studies [44,73], as well as availability of current data (2019 was the last year for which a complete set of data was available). Since this article concerns the use of innovative energy technologies contributing to externalisation of negative externalities in road transport, this study included:

- x_1—the share of renewable energy sources used in transport in 2019 (in %);
- x_2—the share in the market of electric passenger vehicles in 2019 (in %);
- x_3—the share in the market of electric lorries in 2019 (in %);
- x_4—the share in the market of hybrid passenger vehicles in 2019 (in %);
- x_5—the share in the market of hybrid lorries in 2019 (in %);
- x_6—average CO_2 (*carbon dioxide*) emission from new automobiles in 2019 (in g CO_2/km);
- x_7—average CO_2 emission from new lorries in 2019 (in g CO_2/km).

In order to assess the selected variables, a Pearson correlation matrix for these variables was established (Table 1). An excessively high correlation between characteristics may indicate multicollinearity. For this reason, the threshold for the correlation coefficient was set at (r* = 0.9) [74]. Due to the low values of coefficients in this study, no variable was eliminated.

Table 1. A Pearson correlation matrix for the investigated variables.

Variable	x_1	x_2	x_3	x_4	x_5	x_6	x_7
x_1	1.00	0.81 *	0.76 *	0.60 *	0.37	0.10	0.28
x_2	0.81 *	1.00	0.76 *	0.53 *	0.34	−0.27	0.27
x_3	0.76 *	0.76 *	1.00	0.38	0.37	−0.04	0.24
x_4	0.60 *	0.53 *	0.38	1.00	0.29	0.15	0.22
x_5	0.37	0.34	0.37	0.29	1.00	0.02	0.01
x_6	0.10	−0.27	−0.04	0.15	0.02	1.00	0.56 *
x_7	0.28	0.27	0.24	0.22	0.01	0.56 *	1.00

* Correlation coefficients are significant with $p < 0.0500$. Source: own study.

It should be mentioned here that the authors made an attempt at a comprehensive approach to the analysed phenomenon. In previous studies, no division was made into types of vehicles (passenger cars vs. lorries) or types of engines. In view of the above, the authors believe that the presented analysis will fill the gap in current knowledge on the subject.

Within this study, three groups of research methods were applied: (1) collection of empirical material, (2) data processing, as well as (3) presentation of research results.

When collecting research material, the authors used the method of critical literature review and the documentation method. This article presents results of both Polish and foreign studies concerning negative externalities generated by road transport, as well as innovations introduced by the energy sector aiming at their externalisation. Selected legal regulations were also presented in relation to the investigated problem. In turn, the documentation method consisted of the use of reports produced, e.g., by the OECD (*Organisation for Economic Cooperation and Development*) or ACEA (*the European Automobile Manufacturers Association*) in order to collect required data.

When processing the research material, the authors applied the agglomerative clustering technique, which is a representative of the hierarchical method. The distance between the objects (here, selected EU countries) was determined based on the Euclidean distance. In turn, to estimate the distance between clusters, the Ward method was used. This method differs from the others, as it uses the analysis of variance approach, i.e., it attempts minimisation of the sum of squares of deviations within the clusters. The Ward method is considered to be efficient, although its application leads to the formation of small-sized clusters [75]. The analysis provided a dendrogram, constituting a graphical interpretation of obtained results. The method adopted has previously been used to solve similar problems, see: Gostkowski et al. [76], Kacperska et al. [73].

It needs to be stressed here that the variables included in this study were expressed in different units. For this reason, prior to their analysis, the clusters were normalised. It results from the analysis of literature on the subject that the best formal properties among the normalisation methods are found for zero unitisation [77]. Normalisation formulas for the variables are stimulants, i.e., those for which the higher the value, the better, and the variables are destimulants, i.e., those for which the lower the value, the better, took the following form:

$$Z_{ij} = \left(x_{ij} - \min_i x_{ij}\right) / \left(\max_i x_{ij} - \min_i x_{ij}\right),\ x_j \in S \tag{1}$$

$$Z_{ij} = \left(\max_i x_{ij} - x_{ij}\right) / \left(\max_i x_{ij} - \min_i x_{ij}\right),\ x_j \in D \tag{2}$$

where:

Z_{ij}—normalised value of *j*-th variable for *i*-th object (here, an EU country).

x_{ij}—value of *j*-th variable in *i*-th object;

$\max_i x_{ij}$–$\min_i x_{ij}$—range of *j*-th variable.

The set of stimulants was denoted as *S*, while that of destimulants was denoated as *D*. The former set comprised variables x_1, x_2, x_3, x_4 and x_5, while the latter set consisted of x_6 and x_7.

Using the formulas given above, the normalised values from the range of <0;1> were obtained. In this case, for variables which were stimulants, the value of 1.0 was given for the EU countries, in which case, the following variables—the share of use of renewable energy sources in transport in 2019, the share in the market of electric passenger vehicles in 2019, the share in the market of electric lorries in 2019, the share in the market of hybrid passenger vehicles in 2019 and the share in the market of hybrid lorries in 2019—were the highest. In turn, in the case of destimulants, the value of 1.0 was given to the EU countries, for which the variables: average CO_2 emission from new passenger vehicles in 2019 and average CO_2 emission from new lorries in 2019 were the lowest.

The results of these analyses are presented applying the descriptive, table and graphical methods. All calculations were made with the use of the *MS Office 365* package and *STATISTICA* software.

4. Results and Discussion

As was observed earlier, the most significant innovations contributing to the elimination of negative externalities of road transport (e.g., g CO_2/km) include renewable energy sources, as well as low-emission vehicles (electric and hybrid cars).

It needs to be mentioned here that in recent years, the use of renewable energy sources in transport in the EU countries increased (in 2013 the average share of use of renewable energy sources was 6.89%, while in 2019 it was 9.22%) (Table 2). In the analysed period, the greatest increment in the consumption of renewable energy sources in transport was recorded in Estonia, Portugal, Spain and Greece. The countries in which a decrease was observed in this respect included Austria, Finland and Poland.

Table 2. Changes in the use of renewable energy sources in transport in selected EU countries in the years 2013–2019.

Country	2014	2015	2016	2017	2018	2019	2014 = 100
AT	10.98	11.41	10.58	9.70	9.93	10.05	91.51
BE	5.85	3.92	6.03	6.64	6.71	6.82	116.63
CZ	7.00	6.54	6.50	6.62	6.56	7.84	112.06
DK	6.56	6.43	6.73	6.94	6.92	7.11	108.45
EE	0.42	0.41	0.43	0.42	3.32	6.24	1493.54
FI	24.12	24.56	8.81	18.67	14.77	14.32	59.36
FR	8.25	8.37	8.41	8.77	8.96	9.25	112.11
GE	6.90	6.57	7.01	7.03	7.94	7.63	110.58
GR	1.33	1.10	1.62	4.00	4.11	4.05	305.35
HU	7.00	7.17	7.77	7.73	7.75	8.06	115.08
IE	5.20	5.94	5.16	7.44	7.19	8.92	171.35
IT	5.02	6.51	7.41	6.48	7.66	9.05	180.22
LV	4.08	3.64	2.45	2.27	4.73	4.55	111.75
NL	6.56	5.60	4.76	5.84	9.48	12.33	187.81
PL	6.32	5.69	3.97	4.23	5.72	6.20	98.12
PT	3.67	7.43	7.65	7.91	9.04	9.09	247.86
RO	4.68	5.49	6.17	6.56	6.34	7.85	167.83
SK	7.95	8.63	7.77	6.95	6.99	8.31	104.49
SI	2.88	2.24	1.60	2.57	5.48	7.98	277.57
SE	1.02	1.09	5.17	5.80	6.94	7.61	743.16
SW	18.83	21.49	26.56	26.84	29.70	30.31	160.95
Min.	0.42	0.41	0.43	0.42	3.32	4.05	59.36
Average	6.89	7.15	6.79	7.59	8.39	9.22	241.70
Max.	24.12	24.56	26.56	26.84	29.70	30.31	1493.54

Source: own study.

In the case of the petrol market (including the market of low-emission automobiles) in the years 2014–2019, the following changes could be observed (Table 3):

- This market increased by 3.6 million cars, reaching 9 million cars in 2019;
- In the same period, the number of sold diesel engine automobiles dropped by almost 2 million;
- The number of electric cars within the 6-year period increased to 458,915 vehicles;
- In 2019, the number of sold hybrid electric vehicles was 720,260 higher compared to the year 2014.

Table 3. New cars registered in the EU depending on the type of fuel in the years 2013–2019.

Engine Type	2014	2015	2016	2017	2018	2019	2014 = 100
Petroleum	5,358,452	6,036,564	6,800,116	7,563,739	8,521,418	8,964,034	167.29
Diesel	6,599,462	7,039,611	7,175,630	6,617,051	5,402,079	4,650,558	70.47
Electrically charged including:	69,958	148,027	155,634	218,083	300,258	458,915	655.99
• Electric batteries;	37,517	59,165	63,479	97,667	147,428	284,812	759.15
• Plug-in hybrids.	32,441	88,862	92,155	120,416	152,830	174,103	536.68
Hybrid Electric Vehicles	176,525	218,755	278,729	426,769	598,462	896,785	508.02
Fuel cell	38	176	123	253	266	535	1407.89
Natural gas (CNG)	97,214	78,511	57,609	49,553	65,023	68,581	70.55
Other (LPG + E85)	141,452	140,321	118,430	156,710	164,270	187,378	132.47

Source: own study.

The further part of this study presents the results of a cluster analysis, which was conducted based on values of variables concerning the year 2019. In the first step of these analyses, the variables were subjected to zero unitisation. Its results are given in Table 4. On their basis the following conclusions may be drawn:

- Sweden was the country characterised by the highest share (in %) of use of renewable energy sources in transport and the share (in %) in the market of electric lorries.
- The greatest share (in %) in the market of electric passenger vehicles was recorded in the Netherlands, while it was lowest in Estonia.
- In as many as 14 countries (AT, CZ, EE, GR, HU, IE, LV, NL, PL, PT, RO, SK, SI, SW), the share (in %) in the market of hybrid lorries was 0.00.
- The lowest average CO_2 emissions (in g CO_2/km) from new passenger cars were recorded in the Netherlands, while from new lorries the lowest emissions were recorded in Portugal.

Table 4. Normalised values of variables included in this study.

Country	x_1	x_2	x_3	x_4	x_5	x_6	x_7
AT	0.23	0.22	0.36	0.15	**0.00**	0.23	0.10
BE	0.11	0.20	0.16	0.04	0.07	0.34	0.35
CZ	0.14	0.01	0.04	0.03	**0.00**	0.13	0.07
DK	0.12	0.27	0.28	0.15	**1.00**	0.61	0.55
EE	0.08	**0.00**	**0.00**	0.49	**0.00**	0.09	0.47
FI	0.39	0.45	0.12	**1.00**	0.07	0.52	0.23
FR	0.20	0.17	0.64	0.19	0.29	0.56	0.64
GE	0.14	0.18	0.84	0.24	0.07	0.06	0.06
GR	**0.00**	0.01	**0.00**	0.28	**0.00**	0.51	0.48
HU	0.15	0.11	0.08	0.28	**0.00**	0.05	0.43
IE	0.19	0.26	0.48	0.55	**0.00**	0.55	0.51
IT	0.19	0.04	0.20	0.27	0.50	0.40	0.55
LV	0.02	0.01	**0.00**	0.44	**0.00**	0.16	0.33
NL	0.32	**1.00**	0.64	0.34	**0.00**	**1.00**	0.04
PL	0.08	0.01	0.04	0.39	**0.00**	0.04	0.12
PT	0.19	0.37	0.20	0.13	**0.00**	0.69	**1.00**
RO	0.14	0.04	0.04	0.17	**0.00**	0.26	0.47
SK	0.16	0.01	0.08	0.13	**0.00**	**0.00**	**0.00**
SI	0.15	0.04	0.12	**0.00**	**0.00**	0.28	0.21
SE	0.14	0.07	0.32	0.54	0.21	0.35	0.69
SW	**1.00**	0.75	**1.00**	0.53	**0.00**	0.39	0.40

Source: own study.

The aim of the conducted cluster analysis was to classify selected EU countries into groups differing in the degree of use of innovative energy technologies alleviating negative externalities generated by road transport. The distinguished groups should meet the criteria of internal cohesion, i.e., homogeneity and external isolation (heterogeneity). Figure 4 presents a dendrogram showing the obtained hierarchy of clusters. The horizontal axis represents countries constituting the study sample, while the vertical axis indicates the distance of the linkage, in this case the Euclidean distance.

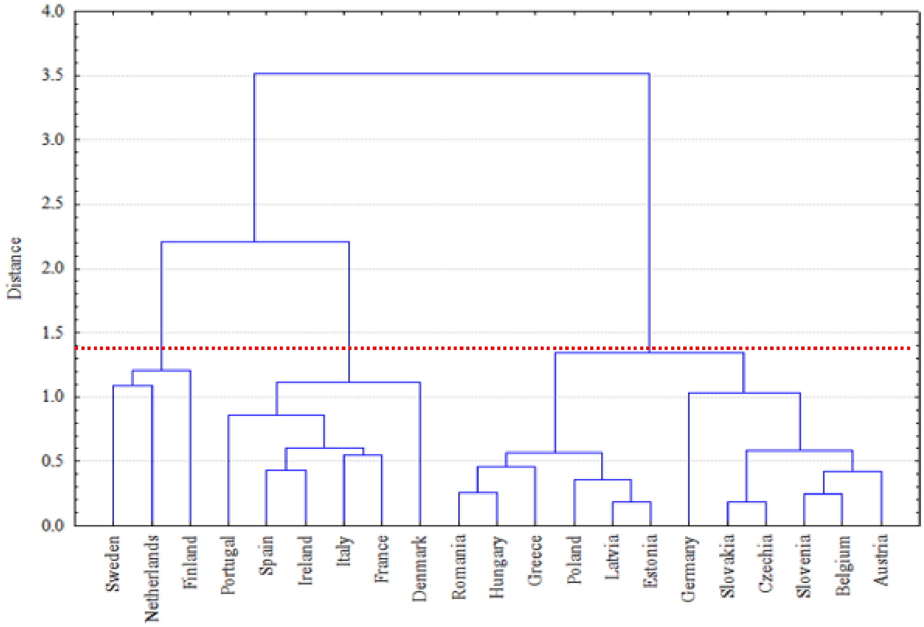

Figure 4. The dendrogram of hierarchical clustering using Ward's method for selected countries from EU. Source: own study.

In order to determine the optimal number of clusters, the graph of agglomeration was used, which presents the distance between clusters at the time of their grouping (Figure 5). The cut-off point was established at the point of a sudden increase in the distance of linkage. In the analysed case, it was between step 18 and 19. Their ordinate corresponds to the distance between linkages amounting to approx. 1.40. For this reason, it was possible to distinguish four clusters (see the broken red line in Figure 4). Their characteristics are given in Table 5.

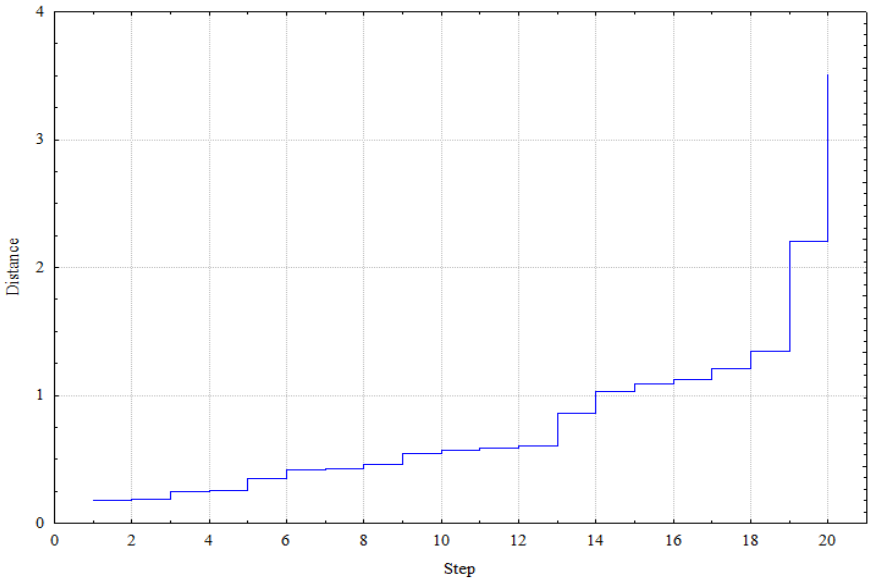

Figure 5. A graph of the distance of linkage in relation to linkage stages. Source: own study.

Table 5. Mean values of variables included in this study at the cross-section of four clusters (legend: green colour marks the highest values for stimulants and the lowest for destimulants; red colour denotes the lowest values for stimulants and the highest values for destimulants).

Variable	Cluster 1	Cluster 2	Cluster 3	Cluster 4
x_1	**18.98%**	8.50%	**6.16%**	8.11%
x_2	**11.07%**	3.18%	**0.75%**	1.92%
x_3	**1.57%**	0.98%	**0.17%**	0.77%
x_4	**9.53%**	6.07%	6.47%	**3.85%**
x_5	0.03%	**0.47%**	**0.00%**	0.03%
x_6	**111.13 g CO_2/km**	114.95 g CO_2/km	126.95 g CO_2/km	**127.33 g CO_2/km**
x_7	166.13 g CO_2/km	**150.50 g CO_2/km**	160.40 g CO_2/km	**169.53 g CO_2/km**

Source: own study.

Cluster 1 comprises three countries: Sweden, the Netherlands and Finland. Compared to the others, this group was characterised by the highest values of four indexes, i.e., the share of use of renewable energy sources in transport in 2019 (on average, 18.98%), the share in the market of electric passenger vehicles in 2019 (on average, 11.07%), the share in the market of electric lorries in 2019 (on average, 1.57%), as well as the share in the market of hybrid passenger vehicles in 2019 (on average, 9.53%). Moreover, in those countries in 2019, new lorries emitted the lowest amounts of g CO_2/km, i.e., 111.13. Thus, it may be stated that this cluster consists of the countries which used innovative energy technologies to the greatest degree to alleviate negative externalities generated by road transport. It needs to be stressed here that in particular, Sweden and Finland, as a rule, are superior to the other EU countries in the realisation of the Green Deal policies. Based on the study conducted by Kisielińska et al. (2021) using the TOPSIS analysis Luxembourg, Austria and Sweden were definite leaders in the use of renewable energy sources in road transport. High values of these indexes were also observed in Finland, France and Germany. This may result, e.g., from the fact that by 2040, Sweden intends to use 100% renewable energy sources [78]. In turn, in Finland, the National Energy and Climate Strategy has been in force since 2017 [79], supporting transition to renewable energy sources (RES). Based on the results obtained, the authors' hypothesis was confirmed.

In turn, cluster 3 was the cluster which was distinguished by the lowest values of variables x_1, x_2, x_3, x_5 and the highest value of variable x_5, and it was formed by Romania, Hungary, Greece, Poland, Latvia and Estonia. It may be stated that these are the countries which were least involved in the alleviation of negative externalities generated by road transport. For example, in 2019, Greece was distinguished by the lowest share of renewable energy sources used in transport (4.05%), Estonia by the lowest share in the market of electric passenger vehicles (0.30%), while Latvia, similar to Greece and Estonia, had the lowest share in the market of electric lorries (0.10%).

We also need to stress the fact that in 2019, countries such as Germany, Slovakia, Czechia, Slovenia, Belgium and Austria (cluster 4) recorded the highest CO_2 emissions from new passenger cars and from lorries in (g CO_2/km). In the case of Slovakia, it was 133.4 g CO_2/km for new passenger vehicles and 174.3 g CO_2/km for new lorries. At the same time, these were the highest values of these indexes for the analysed group of EU countries.

5. Conclusions

The use of innovative energy technologies in road transport became one of the main goals realised by individual EU countries. The number of cars is growing from year to year, resulting in increasing environmental pollution, while deposits of fossil fuels are being depleted.

The aim of the article was to assess and divide selected EU countries into groups differing in the degree of use of energy innovations offsetting negative externalities in road transport. In pursuit of the objective, the national and international literature on energy innovations mitigating negative externalities in road transport was reviewed, changes in the use of renewable energy sources in road transport in EU countries between 2013 and 2019 were presented, and leaders among EU countries in the use of energy innovations in road transport were identified.

This article based on the conducted cluster analysis classified selected EU countries to groups differing in the degree of use of innovative energy technologies alleviating negative externalities generated by road transport. Three countries proved to be leaders—Sweden, the Netherlands and Finland. Compared to the other groups, this group was distinguished by the highest values of four indexes, i.e., the share of use of renewable energy sources in transport in 2019 (on average, 18.98%), the share in the market of electric passenger vehicles in 2019 (on average, 11.07%), the share in the market of electric lorries in 2019 (on average, 1.57%), and the share in the market of hybrid passenger vehicles in 2019 (on average, 9.53%). Countries which had the lowest indexes of the clusters included Romania, Hungary, Greece, Poland, Latvia and Estonia. Thus, the hypothesis stating that only a few EU member countries can be described as leaders in the use of innovative energy technologies in road transport was confirmed.

Based on the conducted study, it may be stated that (1) at present, introduction of innovative energy technologies in road transport is the most advantageous option in terms of alleviating negative externalities generated by road transport, (2) based on the analyses, four groups of clusters were distinguished, (3) a small number of countries (Sweden, the Netherlands and Finland—cluster 1) use innovative solutions (electric passenger vehicles, hybrid passenger vehicles), (4) in 2019, some countries (cluster 4) (Germany, Slovakia, Czechia, Slovenia, Belgium and Austria) were distinguished by the highest CO_2 emissions from new passenger cars and from new lorries, and (5) in order to increase the use of innovative energy technologies in road transport, it is necessary to present their advantages both for humans and the environment.

Despite the realisation of the aim of this article, it needs to be stressed that our study nevertheless has some limitations. The analysis applying cluster analysis was conducted on only three indexes, which were selected based on available data (purposive sampling). Moreover, the division into five groups was applied; as a result, the range between relative closeness indexes between the groups was not identical. Several limitations of the method used should also be borne in mind. Hierarchical clustering methods do not require a prior indication of the number of clusters, but they do require a lot of computing power. The clusters are usually not formed on the basis of any theoretical part. The clusters are rather formed at random. Furthermore, deciding on the right number of clusters is very difficult. Indicating the correct intersection point of a dendrogram requires great precision.

Despite certain limitations, our study constitutes an interesting starting point for future studies. The methodology used in this article may be used to assess the investigated phenomenon in a few or more than a dozen years. Another suggestion would be to use our approach but apply different methods in order to compare obtained results.

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References

1. Rask, K.N. Clean air and renewable fuels: The market for fuel ethanol in the US from 1984 to 1993. *Energy Econ.* **1998**, *20*, 325–345. [CrossRef]
2. Skogstad, G. Mixed feedback dynamics and the USA renewable fuel standard: The roles of policy design and administrative agency. *Policy Sci.* **2020**, *53*, 349–369. [CrossRef]
3. Meisel, K.; Milliniger, M.; Naumann, K.; Müller-Langer, F.; Majer, S.; Thrän, D. Future Renewable Fuel Mixes in Transport in Germany under RED II and Climate Protection Targets. *Energies* **2020**, *13*, 1712. [CrossRef]
4. Wołek, M.; Wolański, M.; Bartłomiejczyk, M.; Wyszomirski, O.; Grzelec, K.; Hebela, K. Ensuring sustainable development of urban public transport: A case study of the trolleybus system in Gdynia and Sopot (Poland). *J. Clean. Prod.* **2021**, *279*, 123807. [CrossRef]
5. Scarpellini, S.; Valero, A.; Llera, E.; Aranda, A. Multicriteria analysis for the assessment of energy innovations in the transport sector. *Energy* **2013**, *57*, 160–168. [CrossRef]
6. Sovacool, B.K.; Noel, L.; Kester, J.; de Rubens, G.Z. Reviewing Nordic transport challenges and climate policy priorities: Expert perceptions of decarbonisation in Denmark, Finland, Iceland, Norway, Sweden. *Energy* **2018**, *165*, 532–542. [CrossRef]
7. Saboori, B.; Sapri, M.; bin Baba, M. Economic growth, energy consumption and CO_2 emissions in OECD (Organization for Economic Co-operation and Development)'s transport sector: A fully modified bi-directional relationship approach. *Energy* **2014**, *66*, 150–161. [CrossRef]
8. Sorlei, I.S.; Bizon, N.; Thounthong, P.; Varlam, M.; Carcadea, E.; Culcer, M.; Iliescu, M.; Raceanu, M. Fuel cell electric vehicles—A brief review of current topologies and energy management strategies. *Energies* **2021**, *14*, 252. [CrossRef]
9. Mounce, R.; Nelson, J.D. On the potential for one-way electric vehicle car-sharing in future mobility systems. *Transp. Res. Part A Policy Pract.* **2019**, *120*, 17–30. [CrossRef]
10. Yildiz, A.; Özel, M.A. A Comparative Study of Energy Consumption and Recovery of Autonomous Fuel-Cell Hydrogen–Electric Vehicles Using Different Powertrains Based on Regenerative Braking and Electronic Stability Control System. *Appl. Sci.* **2021**, *11*, 2515. [CrossRef]
11. Bartolozzi, I.; Rizzi, F.; Frey, M. Comparison between hydrogen and electric vehicles by life cycle assessment: A case study in Tuscany, Italy. *Appl. Energy* **2013**, *101*, 103–111. [CrossRef]
12. Talebpour, A.; Mahmassani, H.S. Influence of connected and autonomous vehicles on traffic flow stability and throughput. *Transp. Res. Part C Emerg. Technol.* **2016**, *71*, 143–163. [CrossRef]
13. Bansal, P.; Kockelman, K.M. Forecasting Americans' long-term adoption of connected and autonomous vehicle technologies. *Transp. Res. Part A Policy Pract.* **2017**, *95*, 49–63. [CrossRef]
14. Schumpeter, J.A. *Teoria Rozwoju Gospodarczego*; Wydawnictwo Naukowe PWN: Warsaw, Poland, 1960; Volume 104.
15. Wojciechowski, M. Innowacje w samorządzie terytorialnym. In *Innowacje 2015. Rozwój Społeczeństwa Informacyjnego w Nowej Perspektywie Finansowej*; Nowak, P.A., Ed.; Urząd Marszałkowski Województwa Łódzkiego: Łódź, Poland, 2015; pp. 117–126. Available online: http://bcpw.bg.pw.edu.pl/Content/5963 (accessed on 5 July 2022).
16. Kaczmarek, B. *Współczesne Wyzwania dla Zarządzania Przedsiębiorstwami*; Towarzystwo Naukowe Organizacji i Kierownictwa Dom Organizatora: Toruń, Poland, 2013; Volume 55.
17. Freeman, C. *The Economics of Industrial Innowation*; F. Pinter: London, UK, 1982; Volume 7.
18. Jashapara, A. *Zarządzanie Wiedzą*; Wydawnictwo Naukowe PWN: Warsaw, Poland, 2006; Volume 91.
19. OECD Eurostat. *Oslo Manual 2018: Guidelines for Collecting and Interpreting Innovation Data*, 3rd ed.; The Measurement of Scientific and Technological Activities OECD Publishing: Paris, France, 2018.
20. OECD Eurostat. *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation*, 4th ed.; The Measurement of Scientific, Technological and Innovation Activities OECD Publishing: Paris, France; Eurostat: Luxembourg, 2018.
21. Łyżwa, E. *Innowacyjność Przedsiębiorstw a Konkurencyjność Regionów*; Wydawnictwo Uniwersytetu Jana Kochanowskiego: Kielce, Poland, 2014; Volume 75.
22. Główny Urząd Statystyczny. Pojęcia Stosowane w Statystyce Publicznej. Available online: https://stat.gov.pl/metainformacje/slownik-pojec/pojecia-stosowane-w-statystyce-publicznej/4253,pojecie.html (accessed on 5 July 2022).
23. International Renewable Energy Agency. *Innovation Priorities to Transform the Energy System—An Overview for Policy Makers*; International Renewable Energy Agency: Abu Dhabi, United Arab Emirates, 2018; Volume 23. Available online: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/May/IRENA_Innovation_priorities_2018.pdf (accessed on 5 July 2022).
24. Zawada, M.; Pabian, A.; Felicjan, B.; Chichobłaziński, L. Innowacje w sektorze energetycznym. In *Zeszyty Naukowe Politechniki Częstochowskiej. Zarządzanie*; Politechnika Częstochowska: Częstochowoa, Poland, 2015; Volume 9, pp. 8–17.
25. Pearson, M.M. 3-Local Government and Firm Innovation in China's Clean Energy Sector. In *Policy, Regulation and Innovation in China's Electricity and Telecom Industries*; Brandt, L., Rawski, T.G., Eds.; Cambridge University Press: Cambridge, UK, 2019.
26. Stec, S.; Szymańska, E.J. Energy innovation of polish local governments. *Energies* **2022**, *15*, 1414. [CrossRef]
27. Okraszewska, E. Znaczenie i uwarunkowania innowacji w sektorze energetycznym. In *Współczesne Problemy Ekonomiczne w Badaniach Młodych Naukowców*; Gruszewska, E., Matel, A., Kuzionko-Ochrymiuk, E., Eds.; Zarządzanie Organizacją, Finanse i Inwestycje; Polskie Towarzystwo Ekonomiczne: Białystok, Poland, 2018; Volume 2, pp. 49–52.
28. Stan, C. *Alternative Propulsion for Automobiles*; Springer International Publishing: Cham, Switzerland, 2017.

29. Boulouchos, K.; Sturm, P.; Kretzschmar, J.; Duić, N.; Laurikko, J.K.; Bradshaw, A.M.; Harmacher, T.; Bettzüge, M.O.; Giannopoulos, G.A.; Poutré, H.L.; et al. *Decarbonisation of Transport: Options and Challenges*; EASAC Policy Report 37; EASAC: Halle, Germany, 2019; Volume 9.
30. Schafer, A. Regularities in travel demand—An international perspective. *J. Transp. Stat.* **2000**, *3*, 1–31. Available online: https://www.bts.gov/archive/publications/journal_of_transportation_and_statistics/volume_03_number_03/paper_01/index (accessed on 25 June 2022).
31. EC. Horizon 2020 Transport Programme. 2018. Available online: https://ec.europa.eu/programmes/horizon2020/en/area/transport (accessed on 3 July 2022).
32. *Key Figures on Europe*; Publications Office of the European Union: Luxembourg, 2021.
33. Lozzi, G.; Cré, I.; Ramos, C. *Relaunching Transport and Tourism in the EU after COVID-19*; European Parliament's Committee on Transport and Tourism: Brussel, Belgium, 2022; Volume 13.
34. Kamińska, T. Koszty i korzyści zewnętrzne transportu. Cz. 1. *Przegląd Komunikacyjny.* **1998**, *7*, 10–16.
35. Huderek-Glapska, S. Efekty zewnętrzne transportu. Aspekty teoretyczne. *Zesz. Nauk. Uniw. Szczecińskiego. Probl. Transp. I Tur.* **2014**, *25*, 83–97.
36. Puławska, S. Koszty zewnętrzne w polityce transportowej Unii Europejskiej. *Transport i Ochrona Środowiska* **2008**, *5–6*, 46–52.
37. Petrović, N.; Jovanović, V.; Nikolić, B.; Pavlović, J.; Mihajlović, J. A comparative analysis of road and rail freight transport through the Republic of Serbia from the aspect of external costs. *Acta Tech. Jaurinensis* **2022**. [CrossRef]
38. Szałankiewicz, K. A Comparative Analysis of the Costs of Transport Service Using Own Fleet and the Transport of an External Company. Ph.D. Thesis, Zakład Inżynierii Systemów Transportowych i Logistyki, Warsaw, Poland, 2021.
39. Van Essen, H.; Fiorello, D.; El Beyrouty, K.; Bieler, C.; van Wijngaarden, L.; Schroten, A.; Parolin, R.; Brambilla, M.; Sutter, D.; Maffii, S.; et al. *Handbook on the External Costs of Transport, Version 2019*; Publications Office of the European Union: Luxembourg, 2020.
40. Heggie, I.G. Management and financing of roads. *World Bank Tech. Pap.* **1995**, *275*, 1–155.
41. Rothengatter, W. External effects of transport. In *A Analytical Transport Economics*; Polak, J.H., Ed.; Edward Elgar Publishing: Cheltenham, UK, 2000; Volume 88, pp. 79–116.
42. Mishan, E.J. The postwar literature on externalities: An interpretative essay. *J. Econ. Lit.* **1971**, *9*, 1–28.
43. Poliński, J. Identyfikacja, estymacja i internalizacja kosztów zewnętrznych transportu. *Probl. Kolejnictwa* **2012**, *156*, 33–67.
44. Kisielińska, J.; Roman, M.; Pietrzak, P.; Roman, M.; Łukasiewicz, K.; Kacperska, E. Utilization of Renewable Energy Sources in Road Transport in EU Countries—TOPSIS Results. *Energies* **2021**, *14*, 7457. [CrossRef]
45. Raczyński, J. Koszty Zewnętrzne w Polityce Rozwoju Transportu. *Tech. Transportu Szynowego Forum Producentów Konstruktorów Użytkowników* **2003**, *7–8*, 12–17.
46. Alonso Raposo, M.; Ciuffo, B.; Alves Dias, P.; Ardente, F.; Aurambout, J.; Baldini, G.; Baranzelli, C.; Blagoeva, D.; Bobba, S.; Braun, R.; et al. *The Future of Road Transport—Implications of Automated, Connected, Low-Carbon and Shared Mobility. EUR 29748 EN*; Publications Office of the European Union: Luxembourg, 2019. [CrossRef]
47. Szaruga, E. Rationalization of the energy consumption of road transport for sustainable development. *Sci. J. Marit. Univ. Szczec.* **2020**, *62*, 36–42.
48. Szaruga, E.; Załoga, E. Rationalization of energy intensity of road transport of member countries of the International Energy Agency. In *Challenges of Urban Mobility, Transport Companies and Systems, Proceedings of the 2018 TranSopot Conference, Sopot, Poland, 28–30 May 2018*; Springer: Berlin/Heidelberg, Germany, 2019.
49. EUR-Lex. Traktat Ustanawiający Europejską Wspólnotę Energii Atomowe. 2022, Dz.U.2004.90.864/3. Available online: https://lexlege.pl/traktat-ustanawiajacy-europejska-wspolnote-energii-atomowej/ (accessed on 15 July 2022).
50. Communication from the Commission to the European Parliament and the Council, A Clean Planet for all. A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy, COM(2018)773, 28 November 2018. Available online: https://www.eumonitor.eu/9353000/1/j9vvik7m1c3gyxp/vktvm72o8kyq. (accessed on 15 July 2022).
51. European Commission. *Energy Roadmap 2050*; Publications Office of the European Union: Luxembourg, 2012.
52. European Parliament. Energy Policy—General Principles. Available online: https://www.europarl.europa.eu/factsheets/pl/sheet/68/polityka-energetyczna-zasady-ogolne (accessed on 15 July 2022).
53. European Commission. The European Green Deal. Available online: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en (accessed on 28 July 2021).
54. European Commission. Komunikat Komisji do Parlamentu Europejskiego, Rady, Europejskiego Komitetu Ekonomiczno-Społecznego I Komitetu Regionów Strategia na Rzecz Zrównoważonej i Inteligentnej Mobilności—Europejski Transport na Drodze ku Przyszłości. Available online: https://data.consilium.europa.eu/doc/document/ST-14012-2020-INIT/pl/pdf (accessed on 28 June 2022).
55. Możliwości Dekarbonizacji Transportu do 2030 r. Available online: https://kib.pl/wp-content/uploads/2019/04/Ecofys-Navigant-2019-Dekarbonizacja-transportu_PL_final_.pdf (accessed on 29 June 2022).
56. Cascetta, E. *Transportation Systems Analysis, Models and Applications*; Springer: Berlin/Heidelberg, Germany, 2009. [CrossRef]
57. Szymanski, P.; Ciuffo, B.; Fontaras, G.; Martini, G.; Pekar, F. The future of road transport in Europe. Environmental implications of automated, connected and low-carbon mobility. *Combust. Engines* **2021**, *186*, 3–10. [CrossRef]

58. Innowacyjność w Transporcie do 2020 Roku—Podstawowe Pojęcia i Tezy. Fundacja Centrum Analiz Transportowych i Infrastrukturalnych (CATI), Warszawa, Listopad 2012. Available online: https://cati.org.pl/download/INNOWACJE/Innowacje%20transportowe%20definicja.pdf (accessed on 5 July 2022).
59. Patel, N.; Bhoi, A.K.; Padmanaban, S.; Holm-Nielsen, J.B. *Pojazdy Elektryczne: Nowoczesne Technologie i Trendy*; Springer: Singapore, 2021; pp. 285–292.
60. Faraz, A.; Ambikapathy, S.; Thangavel, K.; Logavani, G.A. Prasad, Battery Electric Vehicles (BEVs). In *Electric Vehicles, Green Energy and Technology*; Springer: Singapore, 2021; pp. 137–150.
61. Energy Innovation Needs Assessment. In *Road Transport*; Department for Business, Energy and Industrial Strategy: London, UK, 2019; pp. 10–11.
62. Sulatisky, M.; Hill, S.; Lung, B. Dual-Fuel Hydrogen Pickup Trucks, World Hydrogen Energy Conference Lyon 2006. Available online: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.604.180&rep=rep1&type=pdf (accessed on 30 June 2022).
63. Briguglio, N.; Andaloro, L.; Ferraro, M.; Antonucci, V. Fuel Cell Hybrid Electric Vehicles. In *Electric Vehicles—The Benefits and Barriers*; Soylu, S., Ed.; IntechOpen: London, UK, 2011; Volume 6.
64. Shadidi, B.; Najafi, G.; Yusaf, T. A Review of Hydrogen as a Fuel in Internal Combustion Engines. *Energies* **2021**, *14*, 6209. [CrossRef]
65. Duan, Z.; Zhang, L.; Feng, L.; Yu, S.; Jiang, Z.; Xu, X.; Hong, J. Research on Economic and Operating Characteristics of Hydrogen Fuel Cell Cars Based on Real Vehicle Tests. *Energies* **2021**, *14*, 7856. [CrossRef]
66. Burchart-Korol, D.; Gazda-Grzywacz, M.; Zarębska, K. Research and Prospects for the Development of Alternative Fuels in the Transport Sector in Poland: A Review. *Energies* **2020**, *13*, 2988. [CrossRef]
67. Sterlepper, S.; Fischer, M.; Claßen, J.; Huth, V.; Pischinger, S. Concepts for Hydrogen Internal Combustion Engines and Their Implications on the Exhaust Gas Aftertreatment System. *Energies* **2021**, *14*, 8166. [CrossRef]
68. Lin, P.S. Connected Vehicles and Autonomous Vehicles: Where Do ITE Members Stand. *ITE J.* **2013**, *83*, 12.
69. Neufville, R.; Abdalla, H.; Abbas, A. Potential of Connected Fully Autonomous Vehicles in Reducing Congestion and Associated Carbon Emissions. *Sustainability* **2022**, *14*, 6910. [CrossRef]
70. Ahmed, H.U.; Huang, Y.; Lu, P.; Bridgelall, R. Technology Developments and Impacts of Connected and Autonomous Vehicles: An Overview. *Smart Cities* **2022**, *5*, 382–404. [CrossRef]
71. Walters, J.G.; Marsh, S.; Rodrigues, L. Planning Perspectives on Rural Connected, Autonomous and Electric Vehicle Implementation. *Sustainability* **2022**, *14*, 1477. [CrossRef]
72. Alam, M.S.; Georgakis, P. The State of the Art of Cooperative and Connected Autonomous Vehicles from the Future Mobility Management Perspective: A Systematic Review. *Future Transp.* **2022**, *2*, 589–604. [CrossRef]
73. Kacperska, E.; Łukasiewicz, K.; Pietrzak, P. Use of Renewable Energy Sources in the European Union and the Visegrad Group Countries—Results of Cluster Analysis. *Energies* **2021**, *14*, 5680. [CrossRef]
74. Strzała, K.; Przechlewski, T. *Ekonometria Inaczej*; Wydawnictwo Uniwersytetu Gdańskiego: Gdańsk, Polska, 1994.
75. Stanisz, A. *Przystępny kurs Statystyki z Zastosowaniem STATISTICA PL na Przykładach z Medycyny*; Analizy Wielowymiarowe; StatSoft: Cracow, Poland, 2007; Volume 3.
76. Gostkowski, M.; Rokicki, T.; Ochnio, L.; Koszela, G.; Wojtczuk, K.; Ratajczak, M.; Szczepaniuk, H.; Bórawski, P.; Bełdycka-Bórawska, A. Clustering Analysis of Energy Consumption in the Countries of the Visegrad Group. *Energies* **2021**, *14*, 5612. [CrossRef]
77. Kukuła, K. Propozycja budowy rankingu obiektów z wykorzystaniem cech ilościowych oraz jakościowych. *Metod. Ilościowe W Bad. Ekon.* **2012**, *1*, 5–16.
78. Fischer, R.; Elfgren, E.; Toffolo, A. Energy Supply Potentials in the Northern Counties of Finland, Norway and Sweden towards Sustainable Nordic Electricity and Heating Sectors: A Review. *Energies* **2018**, *11*, 751. [CrossRef]
79. National Energy and Climate Strategy of Finland for 2030. Available online: https://www.iea.org/policies/6367-national-energy-and-climate-strategy-of-finland-for-2030 (accessed on 12 June 2022).

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Article

Corporate COVID-19-Related Risk Disclosure in the Electricity Sector: Evidence of Public Companies from Central and Eastern Europe

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Abstract: Risk disclosures contribute to financial stability by providing stakeholders with a better understanding of companies' risk exposures and risk management practices. Presently, corporate risk has been accelerated by the COVID-19 pandemic, and the level of disclosure varies across industries, companies, and organizations. Due to the strategic importance of the energy industry, the paper aims to assess COVID-19-related risk disclosure in the biggest electricity companies in Central and Eastern European countries, and to identify the main determinants of the disclosure. For this purpose, risk disclosure was assessed based on publicly available data disclosed by the 10 biggest public electricity companies operating in this region. Our findings indicate that factors such as the company's size, leverage, and profitability do not significantly affect COVID-19-related risk disclosure in financial reports; nevertheless, COVID-19 risk disclosure in non-financial reports is significantly correlated with the company's assets and revenues. Moreover, there is a significantly strong positive relationship between the scope of COVID-19-related risk disclosure in the management reports and the number of women on the company's management board. COVID-19-related risk disclosure in management board's reports is significantly higher than disclosure in non-financial reports and explanatory notes of financial statements. Our results suggest that risk disclosure is needed to mitigate information asymmetry, especially in pandemic situations.

Keywords: energy industry; electricity; COVID-19; risks; risk disclosure; determinants

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1. Introduction

COVID-19 has been one of the most disruptive and transformative events in a generation. This pandemic has created a new kind of risk, which has resulted in logistical, health, and financial issues that many companies did not see before. In particular, it made business circumstances more volatile, unpredictable, and risky, which can be identified in annual reports, and financial and non-financial disclosure. Corporate risk reports reveal a forward-looking awareness of potential business risks related to the COVID-19 crisis, which is leading to stock market developments. Nevertheless, the awareness of COVID-19 and corporate risk disclosure in this matter differs substantially between industries [1], as well as among developed versus developing countries.

Corporate risk disclosure is the subject of numerous scientific studies. The research so far concentrates on general risk disclosure issues, such as the corporate risk-related disclosure practices in different countries [2–6], risk disclosure rules and determinants [3], [7,8], corporate governance practices and their effect on risk disclosure [4], managers' economic incentives for risk reporting [9], and risk disclosures in the financial crisis [10]. Nevertheless, there is still a little research on risk disclosure in times of uncertainty such as during pandemics [11].

The COVID-19 pandemic opens a new chapter in risk management and corporate risk disclosure. Its novum led to a high degree of uncertainty and huge challenges to the development of the global economy, many industries, and companies. The research conducted so far indicates that COVID-19-related risk disclosure has been explored from the perspective of a particular country, such as the UK [1], the USA [12], Australia [13], and China [14]. In turn, Roberts et al. [15] revealed that only 15.5 percent of companies disclosed anything related to pandemic risk, whereas over 70 percent of reporting companies use a boilerplate, providing minimal useful information to stakeholders. Companies had little incentive to consider and/or disclose pandemic risk so only a few companies were doing so as a practice [16]. Thus, this may imply difficulties in assessing the performance of enterprises by their stakeholders, as well as intended use to conceal unfavorable information. Despite existing regulations on disclosing financial and non-financial information about risks, there is no standardized methodology for providing risk disclosures, which further complicates the assessment of risks identified in a pandemic. This exposes a legislative gap regarding reporting in crisis situations.

In this paper, we focus on the COVID-19 pandemic-related risk disclosure by electricity companies, as well as on the company's determinants on this risk disclosure. To the best of our knowledge, there are no studies of risk disclosures by electricity companies in Central and Eastern European Countries (CEECs). Moreover, there are no studies on the impact of financial results on the scope of COVID-19 risk disclosure so far. There are also no studies using corporate reporting theories to support the assessment of such disclosure. In our opinion, the need to give stakeholders an account of the risks associated with a sudden crisis, such as that of a pandemic, is connatural to the principles of sustainability. Therefore, corporate COVID-19-related risk disclosure may be interpreted in the light of theories of corporate financial reporting and sustainability reporting, such as legitimacy theory, stakeholder theory, institutional theory, signaling theory and political cost theory, as presented in this paper. Therefore, the research gap of the study is an existing research niche in the field of assessment of corporate COVID-19-related risk disclosure and its determinants, as well as their interpretation in the light of corporate reporting theory.

Our research is focused on the energy sector due to its specific business risk and its huge importance to the economy's stability, as well as its environmental sensitivity. The energy industry is one of the most essential pillar industries of economies, and thus the COVID-19 pandemic has affected the energy industry on all fronts [17]. Sudden lifestyle change has dramatically increased the residential electricity demand and reduced electricity demand in business and industry and that eventually affects the national energy demand profile, and also, the results affect energy cost [16]. COVID-19 has heavily impacted stock prices in the energy sector, with this industry among the worst affected [17]. According to some research [18], companies in the energy sector publish higher-quality integrated reports than companies in the other sectors; nevertheless, risk disclosures' completeness depends on the operation sector. Moreover, the energy sector is one of the least COVID-19-related risk disclosure sectors [15].

The hierarchy of energy corporate risk factors developed by [19] indicates that each of the nine energy subsectors has a different number of risk factor types. According to this research, the electricity subsector is characterized by the greatest number of risks (after oil and gas) [19]. The other business risk for this subsector is economic transformation toward greener energy in sustainable development. In particular, the EU Taxonomy compass indicates electricity generation using solar photovoltaic technology, concentrated solar power technology, as well as electricity generation from wind power, ocean energy technologies, and hydropower, geothermal energy, from renewable non-fossil gaseous and liquid fuels, and bioenergy. This energy transformation risk has been accelerated by the COVID-19 pandemic [16,20]. At the same time, proliferation of transparency and accountability initiatives in the energy sector are on the rise, including international accounting standards which require more disclosure specifically for energy projects. Thus, proper sustainability risk disclosures are "the most urgent challenge in relation to disclosure and transparency" for the energy industry [21].

The paper aims to assess the COVID-19-related risk disclosure in the biggest electricity companies in Central and Eastern European Countries and to identify the main determinants of the disclosure. This study refers to disclosure issued in the electricity sector in this region, and in particular, it aims to examine whether electricity companies identify their relevant COVID-19-related risk, and whether they attempt to evaluate it and publicly disclose it in financial statements or other reports (like annual reports, management commentary, sustainability reports, integrated reports, and non-financial reports). The paper presents the results of an empirical study of corporate COVID-19-related risk disclosure, assessed and measured based on publicly available data disclosed by the 10 biggest public electricity companies in CEECs (the biggest companies by revenue come from Poland, the Czech Republic, and Romania).

This study may potentially contribute to the scientific and practical debate on the impact of the COVID-19 pandemic on the energy sector in several dimensions. First, as a comparison between different countries, it offers a deeper consideration of the features of the electricity subsector and its risks in the energy market in Central and Eastern Europe. The second contribution of this research is the implementation of a unique research approach in the risk management area—using textual content analysis as a research method we obtained qualitative information in a structured way, which helps to compare difficult to compare narrative disclosure. This study relies on a set of hand-collected data disclosed by energy companies in their reports. This study also contributes to risk management-related literature by offering a broader context of the examination of electricity companies' risk assessment and risk management strategies. Therefore, the research results can be a valuable practical guide for electric companies that are going to prepare their risk reporting under the EU Taxonomy, including reporting according to the Corporate Sustainability Reporting Directive (in annual reports for 2023 and beyond).

The paper is organized as follows. The second section provides a practical and theoretical framework for the research by explaining the premises for the growing importance of corporate risk disclosures in practice and science, and concludes with research hypotheses' development. The third section explains the methodology of the empirical research, whereas the fourth and fifth sections present and discuss the results. The final part presents theoretical and practical implications and limitations, and implications for future research.

2. Practical and Theoretical Underpinning, Literature Review, and Hypotheses Development

2.1. Practical Premises of COVID-19-Related Risk Disclosure

The harmonization process of non-financial disclosure, including risk disclosure, is ongoing, and its completion will contribute to increasing transparency and enhancing the discipline of the market [22]; thanks to this, investors consider increased risk disclosure important for their portfolio investment decisions (i.e., [23,24]). Nevertheless, many companies are still reluctant to provide risk disclosure [22]. This phenomenon may result from voluntary non-financial disclosure, but also from micro factors related to the entity's size, its organizational culture, and the financial situation [25–30], as well as from differences between countries and macro factors (i.e., political, historical, environmental, socio-cultural, and ethical) (i.e., [31,32]). The 2019 coronavirus pandemic is a new important material factor determining corporate risk, risk management, and risk disclosure.

Presently, in the pandemic's time, COVID-19 will rank among the greatest challenges and risks many executives will have faced [12], and it implies numerous risks related to running a business. A widespread health crisis with the unprecedented number of deaths and hospitalizations, and the implementation of protection measures (e.g., quarantines, regional lockdowns, and social distancing) to contain this pandemic have challenged the growth of global economic and business activity [33]. It has resulted in economic slowdowns, widespread business disruptions, and significant hardship [34]. According to [35], there are two main effects of the coronavirus on business activities. First, the spread of the virus encouraged social distancing which led to the shutdown of financial markets, corporate offices, businesses, and events. Second, the heightened business uncertainty led to a flight to safety in consumption and investment. Thus, this crisis has had a material effect on all business operations, including energy price volatility, collateral effects on the finance and banking industries, slower corporate activity, decline in consumer confidence, disruptions with contract manufacturers and disruptions or delays in shipments, reduced corporate profits and capital spending, trouble with the workforce, and soaring inflation. Despite such negative impacts, the COVID-19 crisis also presents unique opportunities for entrepreneurs to come up with creative disruption for the benefit of individuals, organizations, and society [36], used to rebuild the business.

Corporate results will depend to a large degree on future developments of pandemics, which are highly uncertain and cannot be predicted. Thus, corporate risk disclosure becomes more important to capital markets and investors looking for information on portfolio balancing, and ipso facto reporting issuers are expected to reveal specific references to the corona virus's current and possible future impact on an entity's business. Therefore, the financial and reputational consequences of failing to adequately disclose information can be significant. At this moment, risk factors relating to the impact of COVID-19 and the pandemic may be revealed in public information in a financial statement, management's discussion and analysis, and voluntary non-financial disclosure since the coronavirus disease outbreak in 2019.

Risk disclosures have contributed to financial stability by providing stakeholders with a better understanding of companies' risk exposures and risk management practices, for many years. Therefore, various regulators all over the world, in response to the crisis, released disclosure guidance public companies need to address trends and risks that could reasonably affect their financial statements, operations, and business in general. Nevertheless, there is no standardized methodology for corporate risk disclosures that harmonizes corporate disclosure levels, mandatory and voluntary, financial and narrative. Moreover, this uncertain time with no generally accepted rules on risk disclosure may encourage companies to deliberately distort or omit the disclosure of unfavorable (such as threatening risks) information. Even more, according to [37], corporate fraud in the post-pandemic era is becoming more sophisticated and insidious. Therefore, the significant impact of COVID-19 on business activity determines new tasks for reporting issues such as in public companies. The novum of COVID-19 implicates unpredictable risks that are not easily extracted.

The research so far indicates the following determinants of COVID-19 risk disclosure [1,2,7,10,38]: the country development level, corporate size, and board independence are positively and significantly associated with the extent of voluntary risk disclosure [10];

- the country development level, corporate size, and board independence are positively and significantly associated with the extent of voluntary risk disclosure [10];
- risk reporting practices differ among countries, i.e., in the UK and the USA risk reporting practices are consistently better than overall practices, regarding qualitative information as well as quantitative information on risk types [38];
- there is a significant positive relationship between the COVID-19 disclosure and the firm performance disclosure in the annual reports [1].
- both board independence and gender diversity moderate the relationship between the COVID-19-related information and the level of performance disclosure in the annual reports [1];
- the level of COVID-19 disclosure varies from industry to industry; corona-related risk topics and their perceived relevance for different industries can be identified [1];
- cross-country variation in risk disclosure attributes can only partly be linked to domestic disclosure regulation, suggesting that risk disclosure incentives play an important role [7];
- the more detailed risk disclosure provided in the integrated reporting in comparison with management commentary [39];

- there is a positive relationship between COVID-19 disclosure and uncertainty in annual reports [1];
- companies appear to manage their reputation through disclosure of risk-related information [2];
- the presence of independent directors improves the level of risk-related disclosure [2].

Moreover, firms with larger boards exhibit more significant uncertainty in annual reports with COVID-19 disclosure; however, the significance of uncertainty in annual reports with COVID-19 disclosure remains at the same level as different board independence percentages [1].

2.2. Theoretical Premises of COVID-19—Related Risk Disclosure

COVID-19-related risk disclosure, although a completely new phenomenon in business, may be embedded in basic theories of corporate reporting and disclosure. Corporate risk disclosure spans a great range of information and addresses various reasons and dynamics for providing such information and it is a tool in a complex market situation created for demand and supply of information [40]. Assuming that this situation incorporates information asymmetry, adverse selection, and unequal access to information, the risk disclosure may be perceived in the context of system-oriented theories, including legitimacy theory, stakeholder theory and institutional theory, as well as in the context of manager incentives theories (agency theory, signaling theory, and political cost theory). Importantly in international research, environmental factors cause the differences in the corporate reporting environment from one country to another, and subsequently corporate disclosure and the application of its theories will differ among countries [40].

Stakeholder theory forms a theoretical foundation in which to analyze the impact of prior economic performance, strategic posture toward social responsibility activities, and the intensity of stakeholder power on levels of corporate social disclosure [41]. The normative and instrumental aspects of its theory [42] allow us to interpret risk disclosure, in particular COVID-19 -related risk disclosure, in three aspects [43]:

- descriptive aspect—to assess the reporting behavior of a company paying attention to the combination of competing interests of the company and its stakeholders;
- instrumental aspect—to evaluate the achievement of organizational goals and their presentation through reporting;
- normative aspect—to assess compliance with standards and rules based on moral principles assuming that stakeholders have a mandate to influence the organization, and present their expectations which are of significant value to the company.

Legitimacy theory, in turn, sees the risk disclosure as a way for a company to legitimize its existence to society [44–47]. It looks at society as a whole, while the stakeholder theory recognizes some selective groups within the society to be more powerful than others [48]. Thus, risk disclosure may be presented to enhance legitimacy for two major reasons: first, by fulfilling institutional pressures to assure the effectiveness of market discipline; and second, by managing stakeholder perception of a corporation's reputation [47]. According to [48], legitimacy theory seems to be more suitable for organizations working in developed countries, on the other hand, stakeholder theory appears to be most suitable for organizations working in developing countries. Moreover, in less developed countries, a corporation can manage its stakeholders and the pressure to comply with existing legislation is less as compared to the developed countries [48].

According to institutional theory, companies disclose their risk information because of institutional pressure [43–47]. The institutional theory suggests that organizations are influenced by their institutional contexts, which consist of socially constructed norms, myths or rationales [43]. So risk disclosure may not be purely an economic decision, particularly when social and political aspects also need to be considered, and thus managers may consider mimicking other companies' disclosures particularly companies with good reputations, signaling that their risk management systems are equivalent to the industry standard [49].

Manager incentives theories suggest that managers would like to reduce information asymmetry by disclosing more information. Signaling theory may perceive risk disclosure as an instrument for gaining a competitive advantage, because it assumes that companies give information voluntarily to the capital market in order for firms to compete successfully in the market for risk capital [48]. Agency theory, in turn, conceives of disclosure as a mechanism which decreases the costs resulting from conflicts between managers and shareholders (compensation contracts) and from conflicts between the firm and its creditors (debt contracts) [50].

Due to political cost theory, certain groups of voters have an incentive to lobby for the nationalization, expropriation, break-up, or regulation of an industry or corporation [51]. It means that by avoiding the attention that "high" profits draw attention because of the public's association of high reported profits and monopoly rents, management can reduce the likelihood of adverse political actions and, therefore, reduce its expected costs [51]. Therefore, business organizations have to be concerned with different socio-political factors that raise cost and controversy [52]. Political cost theory assumes that as larger firms are subject to larger public visibility, which causes them to be exposed to greater regulatory actions by the government or to be expected to take more social responsibility [53,54]. This size hypothesis emphasizes the concern of the press and politicians with size of profits and potential monopoly abuses, highlight that companies with high profits are "obvious targets for public criticism" [53].

Such multi-theoretical perspectives of risk disclosure help to develop the hypothesis of the paper.

2.3. Hypotheses Development

Due to the level of COVID-19 risk disclosure varying from industry to industry [1], we choose the energy sector because—according to the authors' knowledge—no prior work has fully determined COVID-19 risk disclosure in this industry. Energy companies are often perceived as the riskiest type of companies to invest in [55,56], and they are exposed to various risk factors. During the COVID-19 pandemic, the energy sector suffered from a higher risk perception [57], and the crisis influenced the energy market structure [58–61]. Moreover, the global spreading of COVID-19 caused numerous impacts on the sustainability of worldwide production and consumption of various commodities, which also contributed to the growing expectations of transforming energy companies by many stakeholders, such as governments, policymakers, and international organizations worldwide, to increase the use of renewable energy sources and improvement of energy efficiency. We also focus on electricity companies because of the business challenges they will face in making several transformations in the coming years [62,63]. All analyzed countries have put in a lot of effort in recent years to adjust their energy systems to the European Union energy policy, which is to create an internal energy market for all Member States. Moreover, after the accession to the EU, they have taken the responsibility to reduce emissions of environmentally harmful greenhouse gases, which requires a large investment in the construction and modernization of the existing outdated energy infrastructure [64,65].

Taking into account the above premises, we base our empirical study on research results [19] that reveals electricity subsector is characterized by the greatest number of risks in the energy sector (after oil and gas), and its risk factors and their importance proportion are following: financial condition (14.45%), energy price (12.00%), regulation (11.99%), power transmission (9.00%), M&A (8.95%), capital market (6.20%), the stock market (5.17%), weather conditions (5.12%), cost (5.01%), and obligations (4.99%). Therefore, we analyze the content of COVID-19-related risk disclosure of the biggest public electricity companies by revenue from CEECs (the analysis of the revenue indicated public companies from Poland, the Czech Republic, and Romania) in the light of the following determinants:

1. corporate size,
2. leverage,
3. corporate profitability,

4. board gender diversity (number of women on board),
5. the way/the method of most risk disclosure (financial statement, management commentary, integrated report, non-financial report)

2.3.1. Corporate Size

The larger firms may have greater incentives to disclose more information to reduce agency costs, hence reducing information asymmetries between managers and shareholders [6]. Previous risk disclosure studies found that a relationship between the company's size and the level of risk disclosures exists. For example, a company's size has a significant positive effect on corporate risk disclosure in the UK [29], in Portugal [2], and in Italy, size was positively related to the number of risk disclosures but no association was found between quality of risk disclosure and size in Italy [66], in Malawi [67], in Malaysia [68], in banks of emerging Islamic countries [3], in Japan [69], Greece [5], the USA, UK, Germany, Canada [7], India [4], China [70], the Netherlands [9], manufacturing companies in key South-East Asian countries [10], non-Asian countries [15], and in 20 European countries [8].

Risk disclosure was not related to size in the UK [6], Italy [66], the UK FTSE companies [71], in Sub-Saharan Africa [72], and China [14].

Exploring the relationship between COVID-19 disclosure and total assets as the measure of the company's size in UK companies, no significant relation was found [1].

Given the above, hypothesis 1 (H1) can be formulated as follows:

Hypothesis 1 (H1). *There is a positive relationship between theelectricity company's size and the scope of COVID-19-related risk disclosure.*

2.3.2. Leverage

Considering the agency theory perspective, creditors of highly leveraged companies should have greater incentives to recommend that management disclose more information. Agency theory predicts that corporate disclosure is expected to increase with leverage [5,6]. However, the empirical evidence for this hypothesis is contradictory [6]. For example, a company's leverage has a significant positive effect on corporate risk disclosure in Portugal [2], and gearing was positively related to the number of risk disclosures, but no association was found between the quality of risk disclosure and gearing in Malawi [67], the USA, UK, Germany, and Canada [7], and capital structure is significantly and negatively related to quantitative risk information in Chinese financial companies [70], in the Netherlands [9], and in 20 European countries [8]. However, leverage was found to have an insignificant association with the level of risk disclosure in the UK [6,29], in UK FTSE companies [71], in Australia [73,74], in Sub-Saharan Africa [72], in Greece [5], and in China [14]. According to the other research, the leverage control variable is significant, but the opposite—companies, which have more leverage, disclose fewer risk disclosures, not more [10]. These arguments lead to the following second hypothesis:

Hypothesis 2 (H2). *There is a positive relationship between the electricity company's leverage and COVID-19-related risk disclosure.*

2.3.3. Corporate Profitability

According to agency theory and political cost theory, companies with more profit may be more encouraged or forced to present more risk disclosure. Profitability is significantly positively associated with risk disclosure in Netherlands [9], in Australia [73], [74], and in Sub-Saharan Africa [72]. The results also show that there is no significant relationship between the number of risk disclosure and the level of the relative profitability of the sample companies in Japan [69], manufacturing companies in key South-East Asian countries [10], in 20 European countries [8], in Polish energy companies [75], China [14], and in UK companies [1,76]. The results indicate a negative and significant association between firm growth (FG) and corporate risk disclosure [4]. These results lead to the third hypothesis:

Hypothesis 3 (H3). *There is a positive relationship between the electricity company's profitability and COVID-19-related risk disclosure.*

2.3.4. The Board Gender Diversity (Number of Women on Board)

Gender on the management board may explain differences in companies' behavior. Nielsen and Huse [77] found that women directors influence board strategic involvement through their contribution to board decision-making, which in turn depends on women directors' professional experience and the different values they bring. Women on the board made a positive and significant impact on risk disclosure in India [4], and COVID-19 disclosure and performance information is higher when there are a higher number of women on the board in UK FTSE non-financial firms [1]. The presence of women on the board was not significantly related to the extent of CSR disclosure in a US context [78]. Women on the board and CEO duality impact ESG disclosure negatively in Latino America [79]. The above arguments lead to the following fourth hypothesis:

Hypothesis 4 (H4). *There is a positive relationship between the board gender diversity of the electricity company and COVID-19-related risk disclosure.*

2.3.5. The Form of Risk Disclosure

COVID-19-related risk disclosure may be published in different statements of the company's annual reporting. Analyzing big companies, it can be stated that they disclose financial and non-financial information in different statements, i.e., explanatory notes of financial statements, management commentary, and non-financial (corporate social responsibility or sustainability) reports. The content of company reports is regulated, but different statements are regulated by different frameworks. Financial statements and explanatory notes to the financial statements are regulated by International Financial Reporting Standards (IAS/IFRS), integrated reporting is regulated by the International Integrated Reporting Council (IIRC) Framework, and social responsibility report is regulated by the chosen framework, but the preparation of management commentary is not regulated by any standards. Italian listed companies the more detailed risk disclosure provided in the integrated reporting in comparison with management commentary [39]. The above arguments lead to the following fifth hypothesis:

Hypothesis 5 (H5). *COVID-19-related risk disclosure provided in the integrated reporting and non-financial report is more detailed than risk disclosure in management commentary.*

From this background, our paper tries to fill the actual gap, by investigating the level of COVID-19-related risk disclosure and the determinants of the risk disclosure.

3. Research Design and Methods

3.1. Sample Selection

The sample consists of the companies obliged to follow the Directive 2014/95/EU on the disclosure of non-financial and diversity information, exceeding both 500 employees and one of the two-dimensional limits (total assets of 20 million EUR and total revenues of 40 million EUR). These are the first 10 largest listed energy (subsector electricity) companies in CEECs, all with a revenue of above 250 EUR million. We collected data on COVID-19-related risk disclosure of the electricity companies: from Poland (PGE S.A., Tauron Polska Energia S.A. (Tauron PE S.A.), Enea S.A., Energa S.A., ZE PAK S.A., Polenergia S.A., Kogeneracja S.A.), from Czech Republik-CEZ a. s., from Romania-Societatea Nationala Nuclearelectrica (SNN Ro), Compania Nationala De Transport Al Energiei Electrice Transelectrica (TRNS).

All included organizations have a fiscal year-end of 31 December. The source of the list is the EMIS list published on 1 January 2022, online at the EMIS database [80].

3.2. Variable Measurement and Data

The period for analysis of COVID-19-related risks disclosure was 2019–2020. This period is significant because it includes the first years of the worldwide COVID-19 pandemic. COVID-19-related risk disclosure analysis started in steps following a process similar to other disclosure studies (e.g., [22,74]). The first step was to identify the disclosure sources from where information will be collected. As annual reports are generally considered to be the most important source of corporate information [5], based on the analyzed financial and non-financial risk disclosure regulations, for our research we identified the following reports:

- financial statements,
- independent auditor's reports,
- explanatory notes to the financial statements,
- management discussion and analysis (management board report, management report),
- non-financial information reports

Using the past literature approach, to measure the extent of COVID-19 -related risk disclosure the authors chose to calculate sentences as the recording unit. We found all sentences about COVID-19-related risk or its risk management information disclosed by the chosen electricity companies. Sentences were included to analyze whether they mentioned the current or future uncertainty of the situation because of the COVID-19 pandemic or its consequences. Keywords such as 'COVID', 'pandemic', 'epidemic', 'SARS', and 'corona' had to appear within any sentence to calculate it into the analysis. Our search was not limited to the risk disclosure section, because risk-related information may be distributed throughout the whole report [15,39]. It should be noted that our instrument captures risk disclosure quantity and does not necessarily its quality [7,81].

Consistent with past studies [10], we define COVID-19-related Risk Disclosure (RD) as the total number of sentences with at least one risk-related keyword:

$$RD_i = \sum RD\_in\_EN_{ij} + \sum RD\_in\_NFR_{ij} + \sum RD\_in\_MBR_{ij}$$

where: RD_i = total number of sentences containing COVID-19-related risk disclosure; $RD\_in\_EN_{ij}$ = number of financial risk sentences for the sentence attribute I in the jth company; $RD\_in\_NFR_{ij}$ = number of non-financial risk sentences for the sentence attribute I in the jth company; $RD\_in\_MBR_{ij}$ = number of risk management sentences for the sentence attribute I in the jth company.

We define all the variables in Table 1.

Table 1. Variables and Their Definitions.

Independent Variable	Definition
RD	COVID-19-related risk disclosure measure.
RD_in_MBR	COVID-19-related risk disclosure measure in Management Board Report
RD_in_EN	COVID-19-related risk disclosure measure in Explanatory notes of financial statements of companies.
RD_in_NFR	COVID-19-related risk disclosure measure in non-financial reporting (Social Responsibility Report, Non-financial Report, Sustainability or Corporate Social Responsibility Report).
ASSETS	Company's size measured as the total assets in the end of the financial year.
REVENUE	Company's size measured as the total revenues at the end of the financial year.
LEVERAGE	Company's leverage measured as the total debt divided by total assets at the end of the financial year.
ROA	Company's profitability is measured by the return-on-assets ratio (ROA).
GENDER	Gender is measured by the number of women in the company's Management Board divided by the total members of the Board.

Source: Own elaboration.

3.3. Statistical Tests

Spearman's correlation coefficient has been calculated using SPSS for testing our hypotheses. The empirical model involved the estimation of Spearman correlation coefficients and the following linear equation:

$$RD = \beta_0 + \beta_1 \times ASSETS + \beta_2 \times LEVERAGE + \beta_3 \times ROA + \beta_4 \times GENDER$$

To test the last hypothesis, we should use the basic parametric test of the normal distribution—*t*-test or the basic nonparametric test Wilcoxon test, which uses the median to calculate statistical significance. The *t*-test and Wilcoxon test analyze the hypotheses, comparing the samples: disclosures in non-financial reporting and disclosures in management board's reports. The *t*-test and Wilcoxon test evaluate by *p*-value. If the value is higher than the chosen significance level, then null hypothesis *H0—disclosed sentences in non-financial reporting and management board's reports do not differ* will be accepted, and if the *p*-value < 0.05, we can state that differences exist and conclude that disclosed sentences in non-financial reporting and management board's reports differ significantly.

The Kolmogorov–Smirnov and Shapiro–Wilk tests are used for the analysis of data distributions. These tests were used to verify the normality of COVID-19-related risks disclosure sentences. If the resulting *p*-value is less than the significance level ($p < 0.01$ or 0.05), the hypothesis that the data are distributed normally is confirmed.

If the *t*-test will show a significant difference between disclosures in reports, Cohen's D will be calculated because it measures the relative strength of the differences between the means of two populations based on sample data. The calculated value of effect size is then compared to Cohen's standards of small (0.2), medium (0.5), and large (0.8) effect sizes.

4. Results

Table 2 shows the statistics for the variables analyzed. Some companies (Polenergia S.A., Kogeneracja S.A., TRNS) did not disclose the COVID-19-related risk at all—two companies that did not mention the pandemic in a single sentence in any of their 2019 reports. These companies prepared and presented their reports before the announcement of the general quarantine, i.e., on 4 and 10 March.

Table 2. Descriptive Statistics.

	Min	Max	Mean	Median	St. Deviation
RD	0	219	60.65	50.5	56.63
RD in MBR	0	86	29.8	23	31.17
RD in EN	0	111	23.8	18.5	26.81
RD in NFR	0	23	5.95	0	8.91
ASSETS	582.3	18234	7084	3052.45	8741
REVENUE	257.87	10296	3161.43	1699.88	3353.31
LEVERAGE	0.15	0.67	0.48	0.53	0.15
ROA	−0.14	0.08	0	0.03	0.07
GENDER	0	0.2	0.12	0.14	0.11

Source: Own elaboration.

One company (Tauron PE S.A.) disclosed the most COVID-19-related risks in 219 sentences in all reports in 2020, but the total average of disclosed sentences was only 60 sentences. It should be mentioned that the statistics of COVID-19-related risk disclosures have an important difference in 2019 and 2020 (Table 3).

We can conclude that all parameters (minimum, maximum, mean, median, and standard deviation) of COVID-19-related risks disclosures in 2020 were higher than in 2019. Despite the similar values of minimum and maximum in 2019, only half of the companies disclosed information in the management reports and only one company (CEZ a. s.) disclosed information about COVID-19 in non-financial reporting in 12 sentences. However, this company (CEZ a. s.) did not disclose information about COVID-19-related risk in explanatory notes of financial statements, while other companies disclosed in 9 to 30 sentences such information in 2019 (Tauron PE S.A., Energa S.A. presented 29 and 30 sentences accordingly).

Table 3. Descriptive Statistics in 2019 and 2020.

	Min	Max	Mean	Median	St. Deviation
			2019		
RD	12	64	30.5	23	18.2
RD in MBR	0	34	10.6	6	14
RD in EN	0	30	17.7	18	10.6
RD in NFR	0	12	1.7	0	4.5
			2020		
RD	29	219	100.1	98	53.7
RD in MBR	9	97	52	54	28.3
RD in EN	0	111	35.2	27	32.9
RD in NFR	0	23	10.7	10	10.1

Source: Own elaboration.

For 2020, we have a very different disclosure situation because a year later, all the researched companies already disclosed between 29 and 219 sentences about COVID-19-related risks in their annual reports (TRNS and Polenergia, S.A. disclosed the least information; Tauron PE S.A., ZE PAK S.A. disclosed the most information). Almost half of the sentences were in reports of Management Boards, but the number of sentences was evenly distributed, i.e., between 9 and 97 sentences. Then, only one company did not present information about COVID-19-related risks in the Explanatory Notes of financial statements, while other companies disclosed from 9 to 111 sentences containing such information. Companies explained briefly the impact of the COVID-19 pandemic on the going concern principle, financial risk, operational risk, and the activity of the company. Non-financial reporting had a surprisingly weak amount of information about COVID-19-related risk and its impact on companies' social, and environmental activities and the struggle against the pandemic situation because companies disclosed from 3 to 23 sentences, while three companies did not disclose this information at all. Figures 1 and 2 show the situation of the disclosure each year by each company.

In 2019, most disclosures were presented by Energa S.A. and Enea S.A. from Poland, in explanatory notes for financial statement and management report, while Tauron PE S.A. only used for this purpose explanatory notes. At the beginning of the pandemic, the companies from Poland—Polenergia S.A., Kogeneracja S.A., as well as from Romania—TRNS did not disclose their risks to stakeholders in their reports. The only company that disclosed the risks in non-financial reports (and chose this as the only form of risk disclosure) was CEZ a.s. from the Czech Republic. In 2020, in turn, all companies chose non-financial reports as a way for risk disclosure, presenting it in parallel with explanatory notes for financial statement and management report (although with a different disclosure structure).

Correlation analysis (Table 4) of all collected data showed that there are no relations between COVID-19-related risks disclosures and control variables in 2019–2020 because no significant correlation coefficients were found. However, we can identify that COVID-19 risk disclosure (RD_in_NFR) was significantly correlated with the company's assets and revenues and the correlation coefficient is about 0.45. That means that the company's size and disclosure of COVID-19-related risks in non-financial reporting are related as the first hypothesis states.

As the data for 2019 and 2020 were very different, the authors found it useful to calculate correlations separately for each year. However, calculations for 2019 did not find any significant relationship between variables. The analysis of 2020 (see Table 5) showed the significant relationship between the company's assets and revenue and COVID-19-related risk disclosure in explanatory notes of financial statements when the correlation coefficient was about 0.71. In addition, a significantly strong positive relationship (coefficient 0.686) was found between the COVID-19-related risk disclosure in the Management Board's reports and the number of women on the company's management board.

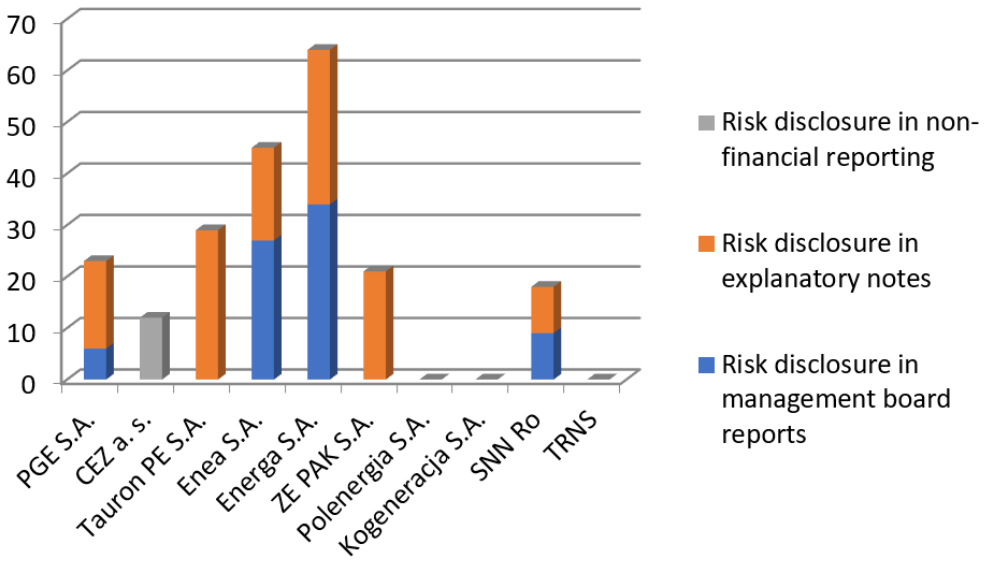

Figure 1. The Structure of Risk Disclosure by Companies in 2019.

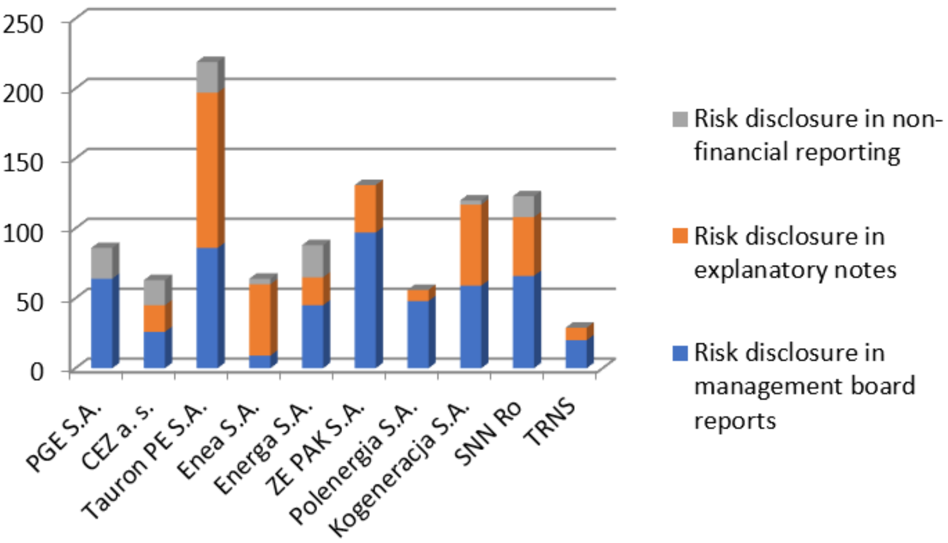

Figure 2. The Structure of Risk Disclosure Information by Companies in 2020. Source: Own elaboration.

Table 4. Correlation Matrix.

	RD	RD_in _MBR	RD_in _EN	RD_in _NFR	ASSETS	REVE-NUE	LEVE-RAGE	ROA	GEN-DER
RD	–								
RD_in_MBR	0.921 **	–							
RD_in_EN	0.746 **	0.524 *	–						
RD_in_NFR	0.574 **	0.456 *	0.272	–					
Assets	0.147	0.007	0.052	0.449 *	–				
Revenue	0.185	0.007	0.067	0.452 *	0.869 **	–			
Leverage	0.276	0.105	0.302	0.243	0.323	0.508 *	–		
Roa	−0.178	0.001	−0.295	0.077	−0.222	−0.394	−0.514 *	–	
Gender	−0.105	0.038	−0.362	−0.019	−0.350	−0.224	0.064	−0.003	–

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). Source: Own elaboration.

Table 5. Correlation Matrix.

	RD	RD_in _MBR	RD_in _EN	RD_in _NFR	ASSETS	REVE-NUE	LEVE-RAGE	ROA	GEN-DER
RD	–								
RD_in_MBR	0.248	–							
RD_in_EN	0.068	0.111	–						
RD_in_NFR	0.406	0.522	0.354	–					
Assets	−0.212	−0.164	0.726 *	0.290	–				
Revenue	0.018	−0.127	0.695 *	0.290	0.915 **	–			
Leverage	0.146	0.146	0.148	0.291	0.280	0.486	–		
Roa	−0.109	−0.158	−0.037	−0.291	−0.061	−0.347	−0.616	–	
Gender	−0.037	−0.686 *	−0.127	−0.418	−0.212	−0.150	0.031	−0.128	–

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). Source: Own elaboration.

The regression analysis of all data showed very weak prediction power because R^2 = 0.05, adjusted R^2 = 0.202. Analyzing only 2020 data R^2 = 0.09, adjusted R^2 = 0.64 (see Tables 6 and 7), and further regression results we see that p levels are too high for rejecting the null hypothesis. Therefore, we may accept H0 which means that we cannot predict the dependent variable (RD—COVID-19-related risk disclosure) with features of our companies such as the company's assets, leverage, ROA, and the number of women in the company's management board.

Table 6. Model Summary.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.299 [a]	0.090	−0.639	36.166

[a] Predictors: (Constant), GENDER, LEVERAGE, ASSETS, ROA Source: Own elaboration.

Table 7. Regression Results for RD as the Dependent Variable.

Model		Unstandardized B	Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	54.830	51.653		1062	0.337
	ASSETS	−0.001	0.002	−0.194	−0.355	0.737
	LEVERAGE	4815	115.746	0.027	0.042	0.968
	ROA	−71.984	228.416	−0.191	−0.315	0.765
	GENDER	−5084	100.512	−0.022	−0.051	0.962

Source: Own elaboration.

The regression analysis proved that the correlations obtained above are random. Therefore, COVID-19-related risk disclosure in the biggest electricity companies cannot be explained with the chosen variables. Our hypotheses should be rejected and it can be stated that there is no relationship between the electricity company's size, leverage, profitability, and board gender diversity and COVID-19-related risk disclosure.

For testing the last hypothesis H5, we need another method. To compare two independent, but related samples of one company usually *t*-test is used. Generally, the null hypothesis for these samples' *t*-test is that two variables have equal population means.

However, this test requires some assumptions: (1) independent observations, and (2) normality—different scores must be normally distributed in the population if the sample size is smaller than 25. Our COVID-19-related risk disclosures data hold independent observations' assumptions because each case holds a separate company that did not interact with other companies. Since we have the sample consisting of 10 companies over two years, we require the normality assumption. The Kolmogorov–Smirnov and Shapiro–Wilk tests (Table 8) were used for testing the normality of the sample.

Table 8. Test of Normality Distribution.

	Kolmogorov–Smirnov			Shapiro–Wilk		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
ASSETS	0.228	20	0.007	0.757	20	0.000
REVENUE	0.271	20	0.000	0.805	20	0.001
LEVERAGE	0.180	20	0.088	0.914	20	0.075
ROA	0.180	20	0.090	0.873	20	0.013
GENDER	0.221	20	0.012	0.840	20	0.004
RD	0.176	20	0.104	0.884	20	0.021
RD_in_MBR	0.198	20	0.039	0.870	20	0.012
RD_in_EN	0.192	20	0.053	0.802	20	0.001
RD_in_NFR	0.348	20	0.000	0.683	20	0.000

Source: Own elaboration.

As the level of significance is $p < 0.05$, we can reject the null hypothesis and state that our two samples are normally distributed. Disclosures of COVID-19-related risk in non-financial and management board reports are likely to be normally distributed in the population. This violates the normality assumption required by the *t*-test. This implies that we should run a *t*-test on these reports (Table 9).

Table 9. Results of T-test.

	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		T	Df	Sig. (2-Tailed)
				Lower	**Upper**			
RD_in_MBR—RD_in_NFR	23.850	28.147	6.294	10.677	37.023	3789	19	0.001

Source: Own elaboration.

We may conclude that the mean difference between risk disclosure in the Management board's reports and non-financial reporting is statistically significant because the level of significance p is 0.001. Our *t*-test shows that COVID-19-related risk disclosure in management board's reports has a higher mean score than in non-financial reporting. Cohen's D is 0.8473 which means that the size of the differences between the means for the two reports is large. Therefore, H5 should be accepted.

5. Discussion

The COVID-19 pandemic has huge and wide-ranging effects, both on economies and businesses. Governments and companies around the world are exposed to the resulting risks for the highly interconnected global economy. Presently, the COVID-19 pandemic states is a new risk component on top of economic and market uncertainty [82] that affects electricity corporations. Therefore, electricity companies are the subject of the research due to their importance in the energy market, as well as to the energy transformation in the European Union. The largest public entities are accepted, counting on their exemplary, transparent disclosures, constituting a model for smaller entities, with lower quality standards of financial reporting. However, research shows significant gaps in disclosures regarding risks and uncertainties during the pandemic, especially in financial and non-financial reporting in 2019.

Considering the characteristics of CEECs, and their business environment, our research tests whether the prevailing theories exist in regards to electricity markets, and it explains the phenomena of corporate reporting and risk disclosure, including COVID-19 related risk, from the perspective of public electricity companies. The obtained results in risk disclosure let us compare corporate reporting in 2019 and 2020. As the pandemic began in the beginning of 2020 and the economic uncertainty suddenly increased, most of the companies were preparing their annual reports with the financial and non-financial results for 2019.

Some companies published their annual reports for 2019 before the global quarantine started, thus avoiding any news of impending risks and post-reporting events in that year's reports. Other companies were able to present the news as post-reporting events and to describe the risks involved, mainly by describing the going concern principle and by commenting on other financial information in the explanatory notes of financial statements. The entities we surveyed presented only some sentences about COVID-19 related risk in the management board's reports, and only one company disclosed 12 sentences about COVID-19 in non-financial reporting in 2019. This phenomenon proves that electricity companies did not provide risk disclosures to stakeholders quickly and in detail. The results of our research cannot be compared with the research on disclosures for 2019 published by energy companies in other countries, as such studies are not available. Nevertheless, our results are in line with the results of research on disclosures by Australian public universities, which COVID-19 risk disclosure for 2019 was minimal in a qualitative, neutral and constant format [13]. Our results are consistent with research results of UK FTSE non-financial firms' COVID-19 disclosures [1] which vary from industry to industry where energy sector is one of three with the lowest COVID-19 disclosures. The identified weaknesses in risk disclosure of 2019 annual reports is also similar to risk disclosure in all global companies presented in [15]—only 6.7 percent of companies from energy sector 6.7 percent considered the potential impact of pandemics.

In 2020, risk disclosures by electricity companies increased. All researched companies disclose risk information, with the most disclosures presented in management board's reports. As the research revealed, most electricity companies presented in their annual reports the impact of the pandemic on both the financial and non-financial performance. Nonetheless, key information regarding COVID-19 related risk were presented in the financial statements, with much less scope in non-financial reports. Some companies even disclosed no information about COVID-19 in their non-financial reporting. This reflects incomplete disclosure and proves that template-based reporting does not take into account new circumstances related to all spheres of sustainable development, also taking into account social and environmental aspects.

The conducted correlation analysis found some significant relationships. COVID-19 risk disclosure in non-financial reporting was significantly correlated with the company's assets and revenues (what is in line with some research such as in [10,25–30]); nevertheless we cannot say the same about the financial and management reporting. The disclosure of COVID-19 related risk information in financial statements and management board's reports does not significantly related with company's size. For 2020, significantly strong relationship between the COVID-19-related risk disclosure in the management board's reports and the number of women on the company's management board let us conclude that the more diversity in the management board of the company, the most likelihood that the company will disclose COVID-19 related risk in its report. The more women on management board, the more information about COVID-19 is provided. These results fall in line with the results obtained by [1,4] that empirically proved a positive and significant impact of a higher number of women on board on risk disclosure.

Results of our research cannot confirm the fact that the risk disclosure of energy sector companies is very qualitative and sufficient, as stated in the previous research [18], comparing disclosures of Polish energy and non-energy companies in 2013–2018. According to the authors [18] the integrated reports in the energy sector is of much higher quality than reports in non-energy sector, and they exceed the legal requirements of disclosing information. Our research; however, does not confirm this phenomenon in the list of pandemic risk disclosures.

Based on the empirical results, we may conclude that at the beginning of the pandemic, the level of risk disclosures was relatively low among the electricity companies, which could have resulted from the surprise of the sudden outbreak of the pandemic. Subsequent reports for 2020 indicate a significant improvement in risk disclosure, which may be interpreted as a way of meeting the information expectations of the stakeholders as well as management of the reputation through disclosure of risk-related information, what is suggested by [2]. The results of our study are contrary to those achieved e.g., by [39], as the more detailed risk disclosure provided in the integrated reporting in comparison with management commentary. Our research subjects disclose risk information mainly in explanatory notes for financial statement and management report, with less use of non-financial reporting for this purpose.

Based on regression analysis, we may conclude that we cannot predict the COVID-19-related risk disclosure with features of our companies such as the company's assets, leverage, and ROA, as suggested in [1,30,76]. Therefore, the disclosure of COVID-19 related risk information is more random than can be explained by any rule. Then unexpected market situations are disclosed unexpectedly, and reporting does not react quickly to the market changes. Nonetheless, for the electricity industry, risk management may be an instrument for accountability and transparency, supporting stakeholder management.

6. Conclusions

The outbreak and rapid spread of COVID-19 have caused great challenges and risks to electricity companies. This study is a voice in the debate on the growing importance of risk reporting and the necessary legislative changes in this area. Our article makes several contributions to the existing theory and research.

6.1. Theoretical Contributions

First, this study enriches the literature stream of theories used for interpreting mandatory and voluntary corporate disclosures. Using the perspective of the corporate reporting theories (legitimacy theory, stakeholder theory, institutional theory, signaling theory and political cost theory) the significance of risk disclosures, including COVID-19-related risk disclosures, is assessed. The indicated weakness of risk disclosure is not yet perceived in the electricity industry as a neither a competitive advantage nor a form of legitimacy, but rather as additional forms of communications for stakeholders. Such an approach is not basically in line with the positive theories explaining the behavior of enterprises toward their stakeholders, nevertheless the pandemic broke out so suddenly and with such force that companies may not have been prepared to quickly adjust their reports. Moreover, our results may also suggest that CEECs have a less mature financial market than developed countries in West. Our results are in line with the assumptions of Omran and Ramdhony [48] that in less developed countries the stakeholder theory's approach is more suitable, because the information provided is more in line with stakeholders' expectations and financial market information needs, and reduces information asymmetries. It means that the normative aspect of stakeholder theory dominates over the descriptive and instrumental aspects. Thus, our results are in contrast with research conducted on Portuguese practices and risk disclosure [2], highlighting the desirability of enhancing accountability by mandating further disclosure of substantive and relevant risk-related information in annual reports.

Moreover, research results reveal that electricity firms disclose COVID-19 risk-related information because they are obliged to do so by institutions, according to institutional theory. Having in mind that the COVID-19 pandemic is an extraordinarily unexpected situation for the global economy, it is difficult to judge why the biggest and most powerful electricity companies in CEECs might not present risk in reports in 2019 in a proper way. As the research proves, a large, profitable, and low-leveraged company is not more likely to provide full disclosure of COVID-19 related risks. Moreover, the study does not confirm that risk disclosure in the electricity industry works as a mechanism to control managers' performance [50]. Therefore, agency theory and political cost theory could not explain the companies' disclosures, in particular in annual reports at the beginning of the pandemic. Thus, the paper discusses theories that recognize actual features of the electricity market in CEECs, mainly information asymmetry and business uncertainties.

Second, this study contributes to the literature of risk reporting and risk management responses to COVID-19 by comparing the scope of disclosures about risks in the largest listed energy (subsector electricity) companies in CEECs in the light of a deeper consideration of the features of the electricity subsector and its risks in the energy market in this region. For this research a unique research approach in the risk management area is used in the form of textual content analysis. This study also contributes to risk management-related literature by filling the research gap concerning the impact of the COVID-19 pandemic on risk disclosure.

Thirdly, this study supplements the literature of risk reporting to cope with this pandemic crisis from management's perspective. Recent studies suggested various response strategies in corporate reporting (like stakeholder capitalism [83]), this study extends it by multi-theoretical approach to formulate a proper risk reporting in crisis. Thus, the research may be interpreted in a broader context of the examination of electricity companies' risk assessment and risk management strategy. It may a be a crucial step toward filling a gap in the theoretical background for corporate risk disclosure research in times of uncertainty.

6.2. Practical Contributions

This study may potentially contribute to the practical debate on the impact of the COVID-19 pandemic on the energy sector. The research results were influenced by the specificity of the electricity market in CEECs, an ownership structure with strong state domination—governmental-owned companies may have weaker expectations of investors toward the disclosure of risk, including the COVID-19 related risks for electricity companies, whereas societal expectations during the pandemic were concentrated on costs and the price of energy. Nevertheless, taking into account market trends in other industries [74,84,85], risk management becomes an instrument of accountability and transparency, supporting stakeholder management. Managers in energy companies are expected to present more transparent risk disclosure, "as the energy transition accelerates to be more just, equitable and inclusive post COVID-19" [21]. Therefore, the research results may be a valuable practical guide for managers in electricity companies that are going to prepare their risk reporting.

Moreover, this study reveals that no standardized methodology for providing risk disclosures results in a diversified scope of disclosures by companies, a different form used, and thus limits the usefulness of the presented information for stakeholders and complicates the assessment of risks identified. It exposes a legislative gap regarding reporting in crisis situations.

6.3. Limitations

We acknowledge that this study is not without limitations. First, the sample selection was limited to companies specifically recognized by the company's assets and revenues, which resulted in the analysis of only ten companies from three countries with a predominance of Polish companies in the sample. Therefore, this prevents us from drawing conclusions about the differences between countries in risk disclosure in the electricity sector. We focus only on one subsector because institutional investors prefer disclosure of firm-specific risk rather than general business risks [24]. Moreover, although all analyzed companies are obliged to follow the Directive 2014/95/EU on the disclosure of non-financial and diversity information, they may reveal risk information as voluntary and mandatory disclosures. Thus, the frameworks of risk disclosure may be different, then the content may differ; thus, it resulted in limited comparability of data. In turn, content analysis, the research method used in this study, also has limitations. Subjectivity could not be eliminated; however, detailed rules and procedures were followed to minimize its effects. In addition, content analysis measures only the quantity, not the quality, of risk disclosure. More disclosure does not necessarily mean better information. Despite these limitations, the findings from this study can provide insight into COVID-19-related risk disclosure.

6.4. Implications for Future Research

As this study was concentrated on the extent of COVID-19 related risk disclosure, future studies should examine the quality and quantity of risk disclosure in more detail. The cross-national comparison among separated CEE countries could also be valuable to better understanding of the specifics of electricity market in this region and the resulting risk disclosures and impacts in particular CEE countries. Future research could also focus on the analysis of the risk disclosure in longer lag period, as the tangible effects of the COVID-19 pandemic may occur after many years and as the effect of a focused stakeholder engagement that is supported by effective communication. A potential for future research may be constituted by other theories than used in the paper, such as behavioral and organizational disclosure theories as well as and resource-based theory, conservative theory and utilitarian theory (like i.e., [86]). In addition, it may be valuable to assess more determinants of COVID-19 related risk disclosure including attributes of the management board, financial performance of the company, ownership, and structure.

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References

1. Elmarzouky, M.; Albitar, K.; Karim, A.E.; Moussa, A.S. COVID-19 Disclosure: A Novel Measurement and Annual Report Uncertainty. *J. Risk Financ. Manag.* **2021**, *14*, 616. [CrossRef]
2. Oliveira, J.; Rodrigues, L.L.; Craig, R. Risk-related disclosures by non-finance companies: Portuguese practices and disclosure characteristics. *Manag. Audit. J.* **2011**, *26*, 817–839. [CrossRef]
3. Grassa, R.; Moumen, N.; Hussainey, K. What drives risk disclosure in Islamic and conventional banks? An international comparison. *Int. J. Financ. Econ.* **2021**, *26*, 6338–6361. [CrossRef]
4. Khandelwal, C.; Kumar, S.; Madhavan, V.; Pandey, N. Do board characteristics impact corporate risk disclosures? The Indian experience. *J. Bus. Res.* **2020**, *121*, 103–111. [CrossRef]
5. Gonidakis, F.K.; Koutoupis, A.G.; Tsamis, A.D.; Agoraki, M.E.K. Risk disclosure in listed Greek companies: The effects of the financial crisis. *Account. Res. J.* **2020**, *33*, 615–633. [CrossRef]
6. Rajab, B.; Handley-Schachler, M. Corporate risk disclosure by UK firms: Trends and determinants. *World Rev. Entrep. Manag. Sustain. Dev.* **2009**, *5*, 224–243. [CrossRef]
7. Dobler, M.; Lajili, K.; Zéghal, D. Attributes of corporate risk disclosure: An international investigation in the manufacturing sector. *J. Int. Account. Res.* **2011**, *10*, 1–22. [CrossRef]
8. Adam-Müller, A.F.A.; Erkens, M.H.R. Risk disclosure noncompliance. *J. Account. Public Policy* **2020**, *39*, 106739. [CrossRef]
9. Deumes, R.; Knechel, W.R. Economic incentives for voluntary reporting on internal risk management and control systems. *Auditing* **2008**, *27*, 35–66. [CrossRef]
10. Probohudono, A.N.; Tower, G.; Rusmin, R. Risk disclosure during the global financial crisis. *Soc. Responsib. J.* **2013**, *9*, 124–136. [CrossRef]
11. Khandelwal, C.; Kumar, S.; Verma, D.; Singh, H.P. Financial risk reporting practices: Systematic literature review and research agenda. *Bottom Line* **2019**, *32*, 185–210. [CrossRef]
12. Benton, R.A.; Cobb, J.A.; Werner, T. Firm partisan positioning, polarization, and risk communication: Examining voluntary disclosures on COVID-19. *Strateg. Manag. J.* **2022**, *43*, 697–723. [CrossRef]
13. Carnegie, G.D.; Guthrie, J.; Martin-Sardesai, A. Public universities and impacts of COVID-19 in Australia: Risk disclosures and organisational change. *Account. Audit. Account. J.* **2022**, *35*, 61–73. [CrossRef]
14. Hao, Y.; Dong, B. Determinants and Consequences of Risk Disclosure: Evidence from Chinese Stock Markets during the COVID-19 Pandemic. *Emerg. Mark. Financ. Trade* **2022**, *58*, 35–55. [CrossRef]
15. Roberts, R.; Jang, D.; Mubako, G. Pandemic risk disclosure in integrated reports: After COVID-19 is hindsight 2020? *Account. Financ.* **2022**. [CrossRef]

16. Elavarasan, R.M.; Shafiullah, G.M.; Raju, K.; Mudgal, V.; Arif, M.T.; Jamal, T.; Subramanian, S.; Balaguru, V.S.S.; Reddy, K.S.; Subramani, U. COVID-19: Impact analysis and recommendations for power sector operation. *Appl. Energy* **2020**, *279*, 115739. [CrossRef]
17. Nguyen, K.H. A coronavirus outbreak and sector stock returns: A tale from the first ten weeks of 2020. *Appl. Econ. Lett.* **2021**. [CrossRef]
18. Piesiewicz, M.; Ciechan-Kujawa, M.; Kufel, P. Differences in disclosure of integrated reports at energy and non-energy companies. *Energies* **2021**, *14*, 1253. [CrossRef]
19. Wei, L.; Li, G.; Zhu, X.; Sun, X.; Li, J. Developing a hierarchical system for energy corporate risk factors based on textual risk disclosures. *Energy Econ.* **2019**, *80*, 452–460. [CrossRef]
20. Fenner, R.; Cernev, T. The implications of the COVID-19 pandemic for delivering the Sustainable Development Goals. *Futures* **2021**, *128*, 102726. [CrossRef]
21. Heffron, R.; Connor, R.; Crossley, P.; Mayor, V.L.I.; Talus, K.; Tomain, J. The identification and impact of justice risks to commercial risks in the energy sector: Post COVID-19 and for the energy transition. *J. Energy Nat. Resour. Law* **2021**, *39*, 439–468. [CrossRef]
22. Leopizzi, R.; Iazzi, A.; Venturelli, A.; Principale, S. Nonfinancial risk disclosure: The 'state of the art' of Italian companies. *Corp. Soc. Responsib. Environ. Manag.* **2020**, *27*, 358–368. [CrossRef]
23. Fortin, A.; Berthelot, S. Md&A risk disclosures and nonprofessional investors' perceptions and investment decisions. *Adv. Account. Behav. Res.* **2012**, *15*, 1–28. [CrossRef]
24. Solomon, J.F.; Solomon, A.; Norton, S.D.; Joseph, N.L. A Conceptual Framework for Corporate Risk Disclosure Emerging From The Agenda For Corporate Governance Reform. *Br. Account. Rev.* **2000**, *32*, 447–478. [CrossRef]
25. Czaja-Cieszyńska, H.; Kordela, D.; Zyznarska-Dworczak, B. How to make corporate social disclosures comparable? *Entrep. Sustain. Issues* **2021**, *9*, 268–288. [CrossRef]
26. Zyznarska-Dworczak, B. *Rachunkowość Zrównoważona w Ujęciu Kognitywno-Teoretycznym*; Wydawnictwo Uniwersytetu Ekonomicznego w Poznaniu: Poznań, Poland, 2019.
27. Zyznarska-Dworczak, B. The impact of the accountability on accounting development as the essence of sustainability accounting. *Probl. Manag.* **2019**, *14*, 73–83. [CrossRef]
28. Samkin, G.; Wingard, C. Understanding systemic change in the context of the social and environmental disclosures of a conservation organisation in a developing country. *Account. Audit. Account. J.* **2020**, *34*, 1275–1304. [CrossRef]
29. Linsley, P.M.; Shrives, P.J. Risk reporting: A study of risk disclosures in the annual reports of UK companies. *Br. Account. Rev.* **2006**, *38*, 387–404. [CrossRef]
30. Szczepankiewicz, E.I.; Loopesko, W.E.; Ullah, F. A Model of Risk Information Disclosures in Non-Financial Corporate Reports of Socially Responsible Energy Companies in Poland. *Energies* **2022**, *15*, 2601. [CrossRef]
31. Buhr, N.; Freedma, M.N. Culture, Institutional Factors and Differences in Environmental Disclosure Between Canada and the United States. *Crit. Perspect. Account.* **2001**, *12*, 293–322. [CrossRef]
32. Zyznarska-Dworczak, B. The development perspectives of sustainable management accounting in Central and Eastern European countries. *Sustainability* **2018**, *10*, 1445. [CrossRef]
33. Kang, J.; Diao, Z.; Zanini, M.T. Business-to-business marketing responses to COVID-19 crisis: A business process perspective. *Mark. Intell. Plan.* **2021**, *39*, 454–468. [CrossRef]
34. Alsharef, A.; Banerjee, S.; Uddin, S.M.J.; Albert, A.; Jaselskis, E. Early Impacts of the COVID-19 Pandemic on the United States Construction Industry. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1559. [CrossRef] [PubMed]
35. Ozili, P.K.; Arun, T. Munich Personal RePEc Archive Spillover of COVID-19: Impact on the Global Economy Spillover of COVID-19: Impact on the Global Economy. *MPRA Pap.* **2020**. [CrossRef]
36. Liu, Y.; Lee, J.M.; Lee, C. The challenges and opportunities of a global health crisis: The management and business implications of COVID-19 from an Asian perspective. *Asian Bus. Manag.* **2020**, *19*, 277–297. [CrossRef]
37. Zhu, X.; Ao, X.; Qin, Z.; Chang, Y.; Liu, Y.; He, Q.; Li, J. Intelligent financial fraud detection practices in post-pandemic era. *Innovation* **2021**, *2*, 100176. [CrossRef]
38. Savvides, S.C.; Savvidou, N. Market risk disclosures of banks: A cross-country study. *Int. J. Organ. Anal.* **2012**, *20*, 379–405. [CrossRef]
39. Manes-Rossi, F.; Nicolo, G.; Orelli, R.L. Reshaping Risk Disclosure through Integrated Reporting: Evidence from Italian Early Adopters. *Int. J. Bus. Manag.* **2017**, *12*, 11. [CrossRef]
40. Von Alberti-Alhtaybat, L.; Hutaibat, K.; Al-Htaybat, K. Mapping corporate disclosure theories. *J. Financ. Report. Account.* **2012**, *10*, 73–94. [CrossRef]
41. Roberts, R.W. Determinants of corporate social responsibility disclosure: An application of stakeholder theory. *Account. Organ. Soc.* **1992**, *17*, 595–612. [CrossRef]
42. Castelo Branco, M.; Lima Rodriques, L. Positioning Stakeholder Theory within the Debate on Corporate Social Responsibility. *Electron. J. Bus. Ethics Organ. Stud.* **2007**, *12*, 5–15.
43. Zyznarska-Dworczak, B. Accounting theories towards non-financial reporting. *Stud. Ekon.* **2018**, *35*, 157–169.
44. Zyznarska-Dworczak, B. Sustainability accounting—Cognitive and conceptual approach. *Sustainability* **2020**, *12*, 9936. [CrossRef]
45. Fernando, S.; Lawrence, S. A theoretical framework for CSR practices: Integrating legitimacy theory, stakeholder theory and institutional theory. *J. Theor. Account. Res.* **2014**, *10*, 149–178.

46. Chen, J.C.; Roberts, R.W. Toward a More Coherent Understanding of the Organization–Society Relationship: A Theoretical Consideration for Social and Environmental Accounting Research. *J. Bus. Ethics* **2010**, *974*, 651–665. [CrossRef]
47. Oliveira, J.; Rodrigues, L.L.; Craig, R. Voluntary risk reporting to enhance institutional and organizational legitimacy: Evidence from Portuguese banks. *J. Financ. Regul. Compliance* **2011**, *19*, 271–289. [CrossRef]
48. Omran, D.; Ramdhony, M.A. Theoretical perspectives on corporate social responsibility disclosure: A critical review. *Int. J. Account. Financ. Rep.* **2015**, *5*, 38–55. [CrossRef]
49. Abraham, S.; Shrives, P.J. Improving the relevance of risk factor disclosure in corporate annual reports. *Br. Account. Rev.* **2014**, *46*, 91–107. [CrossRef]
50. Rodrigues, L.M.P.d.; Oliveira, L.; Craig, R. Applying Voluntary Disclosure Theories to Intangibles Reporting: Evidence from the Portuguese Stock Market. *SSRN Electron. J.* **2011**. [CrossRef]
51. Watts, J.L.; Zimmerman, R.L. Towards a positive theory of the determination of accounting standards. *Account. Rev.* **1978**, *52*, 112–134.
52. Mahmood, Z.; Kouser, R.; Masud, M.A.K. An emerging economy perspective on corporate sustainability reporting—Main actors' views on the current state of affairs in Pakistan. *Asian J. Sustain. Soc. Responsib.* **2019**, *41*, 8. [CrossRef]
53. Milne, M.J. Positive accounting theory, political costs And social disclosure analyses: A critical look. *Crit. Perspect. Account.* **2002**, *13*, 369–395. [CrossRef]
54. Belz, T.; Von Hagen, D.; Steffens, C. Taxes and firm size: Political cost or political power? *J. Account. Lit.* **2019**, *42*, 1–28. [CrossRef]
55. Mazzucato, M.; Semieniuk, G. Financing renewable energy: Who is financing what and why it matters. *Technol. Forecast. Soc. Change* **2018**, *127*, 8–22. [CrossRef]
56. Sadorsky, P. Modeling renewable energy company risk. *Energy Policy* **2012**, *40*, 39–48. [CrossRef]
57. Boldeanu, F.T.; Clemente-Almendros, J.A.; Tache, I. Is ESG Relevant to Electricity Companies during Pandemics? A Case Study on European Firms during COVID-19. *Sustainability* **2022**, *14*, 852. [CrossRef]
58. Szczygielski, J.J.; Brzeszczyński, J.; Charteris, A.; Bwanya, P.R. The COVID-19 storm and the energy sector: The impact and role of uncertainty. *Energy Econ.* **2021**, *109*, 105258. [CrossRef]
59. Amrin, A. An empirical study: Characteristics of business entities and corporate governance on risk disclosure practices. *Bus. Theory Pract.* **2019**, *20*, 25–49. [CrossRef]
60. Cormack, C.; Donovan, C.; Köberle, A.; Ostrovnaya, A. Estimating financial risks from the energy transition: Potential impacts from decarbonization in the european power sector. *J. Energy Mark.* **2020**, *13*, 1–49. [CrossRef]
61. Lin, B.; Su, T. Does COVID-19 open a Pandora's box of changing the connectedness in energy commodities? *Res. Int. Bus. Financ.* **2021**, *56*, 101360. [CrossRef]
62. Fuksa, D.; Bianco, V.; Nowak, W. Opportunities and Threats for Polish Power Industry and for Polish Coal: A Case Study in Poland. *Energies* **2021**, *14*, 6638. [CrossRef]
63. Pilipczuk, O.; Aldieri, L.; Mahapatra, K. Determinants of Managerial Competences Transformation in the Polish Energy Industry. *Energies* **2021**, *14*, 6788. [CrossRef]
64. Norvaiša, E.; Galinis, A. Future of Lithuanian energy system: Electricity import or local generation? *Energy Strateg. Rev.* **2016**, *10*, 29–39. [CrossRef]
65. Pilżys, S. Zmiany w polskim i litewskim sektorze elektroenergetycznym po akcesji do Unii Europejskiej. *Wyzwania Gospod. Glob.* **2012**, *31*, 159–178. [CrossRef]
66. Beretta, S.; Bozzolan, S. A framework for the analysis of firm risk communication. *Int. J. Account.* **2004**, *39*, 265–288. [CrossRef]
67. Tauringana, V.; Chithambo, L. Determinants of risk disclosure compliance in Malawi: A mixed-method approach. *J. Account. Emerg. Econ.* **2016**, *6*, 111–137. [CrossRef]
68. Amran, A.; Bin, A.M.R.; Hassan, B.C.H.M. Risk reporting: An exploratory study on risk management disclosure in Malaysian annual reports. *Manag. Audit. J.* **2009**, *24*, 39–57. [CrossRef]
69. Mohobbot, A. Corporate Risk Reporting Practices in Annual Reports of Japanese Companies. *Jpn. J. Account.* **2005**, *16*, 113–133.
70. Elshandidy, T.; Neri, L.; Guo, Y. Determinants and impacts of risk disclosure quality: Evidence from China. *J. Appl. Account. Res.* **2018**, *19*, 518–536. [CrossRef]
71. Abraham, S.; Cox, P. Analysing the determinants of narrative risk information in UK FTSE 100 annual reports. *Br. Account. Rev.* **2007**, *39*, 227–248. [CrossRef]
72. Agyei-Mensah, B.K.; Buertey, S. Do culture and governance structure influence extent of corporate risk disclosure? *Int. J. Manag. Financ.* **2019**, *15*, 315–334. [CrossRef]
73. Jia, J.; Li, Z.; Munro, L. Risk management committee and risk management disclosure: Evidence from Australia. *Pac. Account. Rev.* **2019**, *31*, 438–461. [CrossRef]
74. Abdullah, M.; Shukor, Z.A.; Mohamed, Z.M.; Ahmad, A. Risk management disclosure: A study on the effect of voluntary risk management disclosure toward firm value. *J. Appl. Account. Res.* **2015**, *16*, 400–432. [CrossRef]
75. Wieczorek-Kosmala, M. Weather risk management in energy sector: The polish case. *Energies* **2020**, *13*, 945. [CrossRef]
76. Elmarzouky, M.; Albitar, K.; Hussainey, K. COVID-19 and performance disclosure: Does governance matter? *Int. J. Account. Inf. Manag.* **2021**, *29*, 776–792. [CrossRef]
77. Nielsen, S.; Huse, M. Involvement: The role of equality perception. *Eur. Manag. Rev.* **2010**, *7*, 16–29. [CrossRef]

78. Giannarakis, G.; Konteos, G.; Sariannidis, N. Financial, governance and environmental determinants of corporate social responsible disclosure. *Manag. Decis.* **2014**, *52*, 1928–1951. [CrossRef]
79. Husted, B.W.; De Sousa-Filho, J.M. Board structure and environmental, social, and governance disclosure in Latin America. *J. Bus. Res.* **2019**, *102*, 220–227. [CrossRef]
80. EMIS, Education Management Information System. 2022. Available online: https://www.emis.com/pl (accessed on 10 January 2022).
81. Botosan, C.A. Discussion of a framework for the analysis of firm risk communication. *Int. J. Account.* **2004**, *39*, 289–295. [CrossRef]
82. Christopoulos, A.G.; Kalantonis, P.; Katsampoxakis, I.; Vergos, K. COVID-19 and the Energy Price Volatility. *Energies* **2021**, *14*, 6496. [CrossRef]
83. Dyczkowska, J.; Krasodomska, J.; Robertson, F. The role of integrated reporting in communicating adherence to stakeholder capitalism principles during the COVID-19 pandemic. *Meditari Account. Res.* **2022**, *30*, 147–184. [CrossRef]
84. Elahi, E. Risk management: The next source of competitive advantage. *Foresight* **2013**, *15*, 117–131. [CrossRef]
85. Yang, S.; Ishtiaq, M.; Anwar, M. Enterprise Risk Management Practices and Firm Performance, the Mediating Role of Competitive Advantage and the Moderating Role of Financial Literacy. *J. Risk Financ. Manag.* **2018**, *11*, 35. [CrossRef]
86. Mobus, J.L. Corporate social responsibility (CSR) reporting by BP: Revealing or obscuring risks? *J. Leg. Ethical Regul. Issues* **2012**, *15*, 35.

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Article

Changes in the Pattern of Weekdays Electricity Real Consumption during the COVID-19 Crisis

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Abstract: In this paper, using data from Romania, we analysed the changes in electricity consumption generated during the COVID-19 crisis, and the measures taken against the spread of the coronavirus to limit the effects of the pandemic. Using a seasonal autoregressive econometric model, we found that, beyond seasonal (weekly, monthly, quarterly, yearly) effects, the average daily electricity real consumption in Romania, during the state of the emergency period (16 March 16 to 14 May 2020) decreased by −194.8 MW (about −2.9%), compared to the historical data (2006–March 2022), and this decrease is not due to the action of some random factors, and it is not a manifestation of domain-specific seasonality. The literature discusses the hypothesis that during the pandemic time, the profile of daily electricity consumption on weekdays was close to the typical Sunday profile. We tested a similar hypothesis for Romania. As a methodology, we tried to go beyond the simple interpretation of statistics and graphics (as found in most papers) and we calculated some measures of distances (the Mahalanobis distance, Manhattan distance) and similarity (coefficient of correlation, cosines coefficient) between the vectors of daily electricity real consumptions, by hourly intervals. As the time interval, we have analysed, for Romania, the electricity real consumption over the period January 2006–March 2022, by day of the week and within the day, by hourly intervals (5911 observations). We found (not very strong) evidence supporting a hypothesis that, in the pandemic crisis, the profile of electricity consumption approaches the weekend pattern only for the state of the emergency period, and we could not find the same evidence for the state of the alert period (June 2020–March 2022). The strongest closeness is to the hourly consumption pattern of Saturday. That is, for Romania, in terms of electricity consumption, "under lockdown, every day is a Sunday" (Staffell) it is rather "under lockdown, every day is (almost) a Saturday"! During the state of the alert period, consumption returned to the pre-crisis profile. Since certain behaviours generated by the pandemic have been maintained in the medium and long term (distance learning, working from home, online sales, etc.), such studies can have policy implications, especially for setting energy policy measures (e.g., in balancing load peaks).

Keywords: COVID-19; power system; hourly electricity consumption

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1. Introduction

The COVID-19 pandemic has affected the economies of most countries worldwide. Glennerster, Snyder, & Tan [1] estimated that the COVID-19 pandemic has caused a reduction in the global economic output by USD 13.8 trillion and has caused over 7 million deaths. Since March 2020, Romania, like other countries, especially in Europe, has imposed specific measures to limit the spread of the SARS-CoV-2 coronavirus and for the medical protection of the population. For this reason, by Decrees of the President of Romania, a state of emergency was established from 16 March 2020 to 14 May 2020. After this date and until 8 March 2022, the state of alert was established through successive decisions of the Romanian Government. During the state of emergency, "taking into consideration the fact that . . . an extraordinary situation, requires exceptional measures", the two decrees instituted measures in "public order, economic, health, and social protection sectors, in justice and foreign affairs domains"; suspended "all educational activities which require physical presence"; isolated people and quarantined localities; closed the border crossing points and the airports; banned meetings, cultural, religious, scientific and sports activities; limited the program of public alimentation units, and so on (in the Annex to the first Decree there are 57 articles with prohibitions, limitations, and recommendations, and in the second, there are 94 articles).

All these restrictions have severely affected economic activities, especially those that involve physical contact between people. Given the nexus between economic activities and energy, the dramatic decline in economic activities, especially during the state of emergency, has also affected energy production and consumption. In Romania, Gross Domestic Product (seasonally adjusted series) fell by −11% in the second quarter of 2020, compared to the fourth quarter of 2019, and by 8.8% compared to the corresponding quarter of the previous year (National Institute of Statistics, [2]). For the entirety of 2020, GDP fell by −3.7% (two percentage points better than in the EU27, where the contraction was −5.7%), and the decrease was recovered in 2021 (+5.1%, while in EU27, the growth was +5.4%)

According to Eurostat data (table nrg_bal_s), regarding energy, primary production decreased in Romania from 24.5 million tonnes of oil equivalent (mil. toe) in 2019 to 22.4 mil. toe in 2020 (−8.8%), while in the European Union—27 countries—the fall was −7.1%, and in the Euro area—19 countries—it was −6.6%. The total primary energy consumption decreased in Romania (2020/2019) from 32.1 to 30.9 mil. toe (−3.6%), less than in the EU27 (−8.7%) and Euro area (−9.6%). The final energy consumption decreased from 23.8 to 23.5 mil. toe (−1.5%), while at the level of the entire European Union, the decrease was −8.1%, and in the Euro area, −9.3%.

The final energy consumption for economic activities fell from 16.121 mils. toe in 2019 to 15.505 mil. toe in 2020 (−3.8%), while for households, the final energy consumption *has grown* from 7753 in 2019 to 8007 mil. toe in 2020, i.e., +3.3%, more than in the EU27 (+0.01%) and Euro area (−0.44%) (National Institute of Statistics, [3]).

According to Eurostat data (table nrg_cb_e), net electricity production in Romania decreased by −5.9% (2020/2019), more than in the EU27 (−4.03%) and recovered by 4% in 2021 (+4.3 in the EU27). Likewise, total electricity final consumption in Romania fell by −3.1% in 2020 (−3.9 for EU27, and −4.4% for the Euro area) and recovered in 2021 (+5.4%), slightly faster than in the EU27 and Euro area (+4.5%). Contrary to the evolution of consumption in economic activities, the household's final electricity consumption grew by +4.9% in 2020, under pandemic restrictions, much more than in EU27 (+1.14%) and in the Euro area (+1.03%).

Regarding the magnitude of the crisis induced by the pandemic, we mention the fact that The Economist [4], estimated that, from March 2020 to October 2022, in Romania, 67,140 people died from COVID-19 and there were 132,530 excess deaths (674 excess deaths/100,000 people, the seventh-highest rate worldwide).

In this paper, we estimated the impact of the COVID-19 crisis on electricity real consumption in Romania. To this end, we built a seasonal autoregressive econometric model and demonstrated that the drop in consumption generated by the pandemic was not caused by random factors (the calculated value for the impact size was statistically significant) and is not a period-specific effect (in the other years, no seasonal effect was identified in the respective period). After searching, we did not find similar estimates in the literature for Romania.

Then, after analysing the average daily consumption, we evaluated a hypothesis according to which the hourly structure of the actual electricity consumption on weekdays did not differ significantly/came closer to the weekend pattern during the COVID-19 crisis. Such a hypothesis has been present in the literature since the start of the COVID-19 crisis. However, the approaches are mainly informed by examples and based on some intuitions without a well-defined methodological basis. The original contribution of our paper consists of discussing and applying a methodology for measuring the effect of the crisis. The proposed methodology uses several techniques to measure the distance/similarity between objects described by several attributes. Currently, such techniques are widely used in the theory of shape analysis and pattern recognition (a fundamental paper in this area was written by Biederman (1987) [5]); another is a book by Da Fontoura Costa and Cesar (2000) [6], classification theory (Batley (2015) [7], Parrochia (2016) [8]), machine learning (Bishop (2007) [9], Banoula (2022) [10]), web search engines (Yang and Gerasoulis (2014) [11], Kameni Homte, Batchakui and Nkambou (2022) [12]), data mining (Han, Kamber, and Pei (2012) [13], Tan et al. (2018) [14]), and information retrieval (Hjørland & Pedersen, 2005 [15]), artificial intelligence (Russell and Norvig (2020) [16], Manyika (2022) [17]), and so on.

By applying four measures (two for distances, two for similarity), to assure methodological robustness, we found some similitude between the shape of electricity hourly real consumption during the first phase of the COVID-19 crisis (the state of the emergency period, i.e., 16 March 2020–14 May 2020), and a profile standard specific to weekend days (as recorded for January 2006 to February 2020). Since certain behaviours generated by the pandemic have been maintained in the medium and long term (distance learning, working from home, online sales, etc.), such studies can have policy implications, especially with regard to setting energy policy measures (e.g., in balancing load peaks).

2. Literature Review

Since March 2020, a vast amount of literature on the evolution and effects of the COVID-19 pandemic has emerged. Many papers provide a literature review: Nicola et al. (2020) [18], Alshater, Atayah & Khan (2021) [19], Brodeur et al. (2021) [20], Callegari & Feder (2022) [21], Podolsky et al. (2022) [22]. Some papers review the literature in specialised fields. For example, Coutinho et al. (2021) [23] have studied the literature concerning how the COVID-19 pandemic has affected people's living conditions, especially the impact on mental health. Şevgin, Alptekin & Şevgin (2021) [24] realised a literature review relating to COVID-19′s impact on the quality of life of the elderly. Rana, Keramat, and Gow (2021) [25] are studying the literature regarding the impact of the COVID-19 crisis on air quality (dynamics of pollutant concentrations). A study by Khlystova, Kalyuzhnova, and Belitski (2022) [26] reviewed 59 papers about the implications of the COVID-19 pandemic on the creative industries (they found positive effects on IT and software and negative effects on cultural activities). Haafza et al. (2021) [27] investigated studies that examine the application of Big Data to diagnosis in public health systems during the pandemic crisis.

Gunasekeran et al. (2022) [28] reviewed the literature concerning the role of social media platforms in public health communication (and identified a potential negative impact on population health, p. 1). Cachón-Zagalaz et al. (2020) [29], Marinoni, van't Land & Jensen (2020) [30], Pokhrel & Chhetri (2021) [31], Shan & Beheshti (2021) [32] and Zancajo (2021) [33] provide a literature review concerning the impact of COVID-19 Pandemic on education systems. Alifuddin & Ibrahim (2021) [34] tried a systematic literature review addressing the COVID-19 Pandemic's impact on work from home. Štreimikienė et al. (2021) [35] review the literature on the effects of the COVID-19 pandemic on agriculture (vulnerabilities, resilience, risks).

By reviewing 18,590 studies and selecting 24 of these for inclusion in a meta-analysis, Herby, Jonung, and Hanke (2022, p. 2) [36] found that, although lockdowns had a huge economic and social cost, in Europe and the USA they had a very small effect on COVID-19-related mortality (only −0.2%, p. 2).

Herby, Jonung, & Hanke [36], Agyei et al. (2022) [37], Sun & Shi (2022) [38] and Owusu Junior (2022) [39] analysed the co-movement between financial variables during the COVID-19 crisis.

Regarding the analysis of the impact of COVID-19 on the energy sector, we mention the paper of Wang, Huang & Li (2022) [40] who investigated studies in the Scopus database that analyse the impact of the COVID-19 pandemic on renewable energy. Chong et al. (2022) [41] reviewed studies in the literature on energy sustainability and carbon neutrality in the post-COVID era and advocated a holistic approach to environmental issues, energy resources, and social well-being. Radtke (2022) [42] discussed the problem of energy democracy. Dogan, Majeed & Luni (2022) [43] analysed the effect of the COVID-19 pandemic on the use of natural resources (including energy). Salisu & Adediran (2020) [44], Pastory & Munishi (2022) [45] and Shaikh (2022) [46] studied the impact of the pandemic crisis on the volatility of energy markets.

Lazo, Aguirre, and Watts (2022) [47] proposed a comprehensive literature review concerning the confinement measures' impact on the electricity sector.

The Applied Energy Review published a Special Issue (March 2021) in which 23 articles analysed the impacts of COVID-19 on energy demand and generation, as well as on the environment.

Cicala (2020, October, pp. 5, 7) [48] estimated for the USA that, in the second quarter of 2020, residential electricity consumption grew by USD 6B (+10%), while the industrial and commercial demand fell by 12% and 14%, respectively. Wang, Li, Cui, Shi, & Mingee (2022) [49] showed an increase in energy consumption in the residential sector in the U.S. continental metropolitan area at the beginning of the pandemic. Li et al. (2022) [50] found that a one percent decrease in the effective reproduction number (secondary cases caused by a primary case) for COVID-19 had a positive impact on global electricity consumption (+1.62%) in Germany and five US states.

García et al. (2021) [51] analysed the impact of COVID-19 restrictions on energy consumption and found that, from March to May 2020, residential consumption in Manzanilla (Huelva, Spain) increased by around 15%, while non-residential consumption fell by 38% (p. 1).

Cortiços & Duart (2022) [52] analysed the increase in energy consumption generated by the need to ensure airflow (ventilation) in large office buildings, to prevent the spread of the virus. Energy consumption in large commercial buildings in Dalian (China) was studied by (Su, Cheng, Wang, & Wang (2022) [53].

By studying 451 buildings in the Canton of Geneva, Todeschi et al. (2022) [54] found that the energy demanded heating and cooling increased during the lockdown.

Through logistic models, applied to 3369 responses to a questionnaire, Balest & Stawinoga (2022) [55] analysed the changes in the daily energy practices of households in Italy during the lockdown caused by the COVID-19 pandemic, in the context of issues related to the energy transition. The authors found that not all household activities were affected by the lockdown (e.g., use of the washing machine), and the change in household energy consumption was influenced by individual and household characteristics (gender, age, type of house, size of the dwelling space and technological context, household income, cultural and regional particularities).

Buechler et al. (2022) [56] and Moses (2022) [57] identified a sharp drop in electricity consumption (by 7.6% in April 2020) for 58 countries during the first phase of the pandemic. However, the consumption recovered completely over the following 6 months. According to the authors, the rapid rebound in consumption was due to the decoupling between economic activity and electricity demand. As a methodology, Buechler et al. (2022) [56] used a panel regression with random individual-specific effects and found, among other things, a relationship between changes in consumption during the pandemic and the pre-pandemic sensitivity of electricity consumption to holidays. On contrary, He & Zhang (2022, p. 1) [58] say that economic growth in OECD countries during the pandemic crises was "impeded" by energy consumption. To identify the demand shift during the pandemic, Narajewski and Ziel (2020) [59] analysed the electricity consumption in Germany, France, Italy, Spain, and Poland.

Zhang et al. (2021) [60] analysed the impact of COVID-19 on energy consumption (including renewable sources) and changes in energy policy. As a methodology, they used an artificial neural network model.

For Romania, Armeanu, Joldeș, and Gherghina (2022) [61] examined the impact of the COVID-19 crisis on the energy market, through the Granger causality tests and Autoregressive Distributed Lag (ARDL) models. They found no long-term relationships between the COVID-19 crisis and the price of electricity or natural gas. In our opinion, this result is determined by the specifics of the analysed period: daily data between 1 July 2021, and 21 December 2021. However, the increase in electricity and natural gas prices was accentuated by the restoration of supply chains and the increasing global demand in the background of the post-crisis recovery process. However, these processes were mainly manifested after January 2022 and after February, the supply deficit in the energy products market was accentuated by the political crisis (the war) in the east of the continent. Andrei et al. (2022) [62] found that the total electricity consumption of Romanian universities decreased between 20% and 36% in 2020, and the electricity due to the use of computers decreased by 75% to 96%. Undoubtedly, consumption was shifted to the households of students and professors!

Regarding the profile of households' hourly electricity consumption, the International Energy Agency (International Energy Agency, 2020, p. 23) [63] notes that, in some countries, the COVID-19 crisis has changed the pattern of "electricity consumption during the weekdays toward a form usually observed on pre-pandemic Sundays". "Under lockdown, every day is a Sunday" is also the hypothesis argued by Staffell (2020, p. 4) [64], Liasi, Shahbazian & Bina (2020) [65] and Mehlig, ApSimon & Staffel (2021) [66] for the United Kingdom, Wilson et al. (2020) [67] and Burleyson et al. (2020) [68] for the United States, Goddard (2020) [69] for Czech Republic, Germany, Spain, Italy, Belgium, and Austria.

Burleyson, Rahman, Rice, Smith, & Voisin (2021) [70] quoted a blog post from an energy market Independent System Operator (NYISO, New York, NY, USA), who reported a special pattern in daily electricity consumption at the beginning of the pandemic, profile similar to a "widespread snow day". Bahmanyar, Estebsari, and Ernst (2020) [71] found analogous patterns in April 2020, for Belgium, Italy, Netherlands, Spain, Sweden, and the UK.

Santiago et al. (2021) [72] found that the electricity demand in Spain decreased by 13% in March–April 2020 (and the CO_2 emissions by 33%) and the hourly profile of consumption changed from the usual pattern—they presented a detailed analysis for Wednesdays and Sundays.

The households' hourly electricity consumption was evaluated by Abdeen et al. (2021) [73] and Rouleau & Gosselin (2021) [74] for Canada, Hinson (2020) [75], Burleyson et al. (2020) [68], Krarti & Aldubyan (2021) [76], Brewer (2022) [77], Ku et al. (2022) [78] for the USA, Cribb, Gotlibovych & Sykes (2020) [79] and Huebner et al. (2021) [80] for the United Kingdom, Benatia (2022) [81] for France, Snow et al. (2020) [82] for Australia, Cheshmehzangi (2020) [83] for China, Bielecki et al. (2021) [84] for Poland (Warsaw region), Carvalho et al. (2020) [85] for Brazil, Bollino & d'Errico (2022) [86] for Italia, Wakashiro (2022) [87] for Japan, Hansell and Vällfors (2021) [88] for Sweden, Khan, and Sahabuddin (2021) [89] and Alavi et al. (2022) [90] for Bangladesh, Bhattacharya et al. (2021) [91] for India, and Abulibdeh, Zaidan & Jabbar (2022) [92] for Qatar.

Rana et al. (2022, p. 1) [93] and Su, Cheng, Wang, & Wang (2022, p. 16) [53] showed that the COVID-19 pandemic has changed lifestyles in the long term, which has lasting effects on energy consumption.

3. Data and Methodology

3.1. Methodology

The data generating process for time series electricity real consumption (ERC) is stationary: the Augmented Dickey–Fuller (ADF) test statistic is −5.680 (while the critical value for 1% level is −3.43) and the Kwiatkowski–Phillips–Schmidt–Shin test statistic is 0.382 (while the asymptotic critical value for 5% level is 0.463). Given the stationarity of the time series, to evaluate the size of the impact induced by the COVID-19 crisis on electricity real consumption (ERC), we built a $SARX(p)(P_s)_s$ = w,m,q,y type model (Jula & Jula, 2019 [94]), with weekly (s_w = 7 days), monthly (s_m = 30 days), quarterly (s_q = 91 days), and yearly seasonality (s_y = 365 days):

$$(1-\varphi_1 L)(1-\varphi_7 L^7)(1-\varphi_{30}L^{30})(1-\varphi_{91}L^{91})(1-\varphi_{365}L^{365})(ERC_t-\mu) = d_{PEREM}+\varepsilon_t \quad (1)$$

In the model, ERC is the daily average of electricity real consumption (in MW) and φ are the parameters corresponding to the autoregressive and multi-seasonal process: φ_1 modelling the autoregressive process of order 1, AR(1), and the other parameters φ are for modelling weekly (φ_7), monthly (φ_{30}), quarterly (φ_{91}) and annual (φ_{365}) seasonality. Additionally, L is the lag operator ($Ly_t = y_{t-1}$, $L^7 y_t = y_{t-7}$ and so on), μ is the mean of the process $\left(\overline{ERC}\right)$, dPEREM are dummy period (interval) variables, and ε is the error variable.

The inclusion of the moving average terms does not significantly improve the model (e.g., the inclusion of an MA term drops the Schwarz Information Criterion (SIC) from 13.6402 to 13.6392 only). Under these conditions, starting from a principle of parsimony—if two specifications lead to close results, the simpler one is preferred (Occam's razor)—we did not include in the model either moving average (MA) or seasonal moving average terms (SMA).

To assess the hypothesis that, in Romania, during the COVID-19 crisis, the hourly structure of real electricity consumption on weekdays day does not differ significantly/is close to the pattern exhibited on weekend days, we evaluated the similarities/differences between the hourly structure of each weekday and the pattern of weekend days consumption.

The literature cites multiple possibilities for measuring the similarity between two or more objects (structures). Metcalf and Casey (2016) [95] discussed metrics and similarities/dissimilarities of numeric attributes, strings, of "sets of sets".

A very well-known technique used to evaluate the dissimilarity between two vectors is the Minkowski distance of order $p \geq 1$ (ScienceDirect, 2022 [96]). Let X = ($x_1, x_2, \ldots, x_n$) and Y = ($y_1, y_2, \ldots, y_n$) be two structures described by *n* numeric characteristics. The Minkowski distance of order $p \geq 1$ is

$$d(X,Y)_{Minkowski} = \left(\sum_{t=1}^{n} |x_t - y_t|^p\right)^{\frac{1}{p}} \quad (2)$$

From the Minkowski distance formula, we can deduce (Han, Kamber, & Pei, 2012, pp. 72–74 [13]):

for p = 1, the Manhattan distance $\left(\sum_{t=1}^{n} |x_t - y_t|\right)$,

for p = 2, the Euclidian distance $\left(\sqrt{\sum_{t=1}^{n} (x_t - y_t)^2}\right)$,

for $p \to \infty$, the Chebyshev distance $\left(\max_{t=1}^{n} |x_t - y_t|\right)$.

A technique that considers the (possibly) different measurement scale of the analysed variables is the Mahalanobis distance:

$$d(X,Y)_{Mahalanobis} = \sqrt{(X-Y)\Sigma^{-1}(X-Y)'}$$

where Σ is the covariance matrix and the apostrophe (′) stands for transposition. The Mahalanobis distances are also used when the variables are correlated (Tan, Steinbach, Karpatne, & Kumar, 2018, p. 116 [14]).

For similarity, the linear correlation coefficient is frequently used. The well-known Pearson formula is:

$$\mathrm{corr}(X,Y)=\frac{\sum_{t}^{n}(x_t-\overline{x})(y_t-\overline{y})}{\sqrt{\sum_{t}^{n}(x_t-\overline{x})^2}\sqrt{\sum_{t}^{n}(y_t-\overline{y})^2}}$$

where $\overline{x}$ and $\overline{y}$ are the means of X and Y, respectively.

A variant of this coefficient—namely the uncentered correlation coefficient, known as the cosine similarity coefficient—is:

$$\cos(X,Y)=\frac{\sum_{t}^{n}x_t y_t}{\sqrt{\sum_{t}^{n}x_t^2}\sqrt{\sum_{t}^{n}y_t^2}}\ \text{or, }\cos(X,Y)=\frac{\langle X,Y\rangle}{\|X\|\|Y\|}$$

where <X, Y> is the inner product and $\|X\|$ is the vector norm. The angle between X and Y is computed using the arccosine function.

We mention that the coefficient of correlation is invariant to scaling (multiplication by a nonzero value) and to translation (adding a constant), while the cosine of an angle is invariant to scaling but not to translation. The Minkowski distance (including the Euclidean, Manhattan, and Chebyshev distance) is neither translation nor scaling invariant (Tan, Steinbach, Karpatne, & Kumar, 2018, pp. 105–108 [14]).

There are other techniques for measuring proximity (similarity/dissimilarity) between objects when the characteristics are of different types, and/or may be of differing importance. We do not detail these techniques because, for the analysis followed in this paper, the structure vectors are constructed starting from the electricity consumption in different time intervals, so that the values are of the same type, the same order of magnitude (scale), and the same importance.

Dobrescu (2011, pp. 7–11) [97] and Jula & Jula (2013, pp. 57–58) [98] analyses ten methods of similarity/dissimilarity: Manhattan distance, Euclidian distance, Canberra distance, Bhattacharyya coefficient, coefficient of correlation (Pearson), the Herfindahl–Hirschman index, the Kullback–Leibler divergence measure, the Jaccard index, the Hellinger distance, and the Cosine similarity coefficient.

To assess changes in energy demand due to the COVID-19 pandemic, Bahmanyar, Estebsari, and Ernst (2020, p. 3) [71] used a so-called Demand Variation Index defined by the following equation:

$$\mathrm{DVI}=\frac{\sum_{i=1}^{n}\left(P_{t_i}^{old}-P_{t_i}^{new}\right)}{n\cdot\overline{P}^{old}}\cdot 100$$

where P is power demand, $\overline{P}^{old}$ is average of power demand over the reference period, t_i—time, n—the number of recorded demands, old—reference period, new—actual period (the symbols are those used by the above-mentioned authors).

This "index" raises some problems: on the one hand, after summing, the positive values $\left(P_{t_i}^{old}-P_{t_i}^{new}>0\right)$ can offset the negative ones $\left(P_{t_i}^{old}-P_{t_i}^{new}<0\right)$, and thus, the DVI index masks the amplitude of the variation. On the other hand, based on simple algebra, the DVI can be written as follows:

$$\mathrm{DVI}=\frac{\sum_{i=1}^{n}\left(P_{t_i}^{old}-P_{t_i}^{new}\right)}{n\cdot\overline{P}^{old}}\cdot 100=\frac{1}{\overline{P}^{old}}\left(\frac{\sum_{i=1}^{n}P_{t_i}^{old}}{n}-\frac{\sum_{i=1}^{n}P_{t_i}^{new}}{n}\right)\cdot 100=\left(1-\frac{\overline{P}^{new}}{\overline{P}^{old}}\right)\cdot 100$$

This means that the DVI of Bahmanyar, Estebsari, and Ernst (2020) [71] can only measure the average change in electricity consumption during the pandemic, compared to consumption in pre-pandemic time. So, DVI cannot assess the closeness (or divergence) between the weekday electricity consumption hourly structures during the pandemic and the weekend consumption profile. Santiago et al. (2021) [72] avoid the compensation problem by considering the difference between the pandemic and pre-pandemic values in absolute value (the Manhattan distance).

In this paper, to assess the degree of similarity/dissimilarity between the hourly electricity real consumption on the weekdays and the corresponding vector for weekend days, we calculate three measurement indicators: the linear correlation coefficient, the Manhattan distance, and the angle between the structure vectors. We also calculate a more complex measure, namely the Mahalanobis distance, even if the values of our vectors are of the same type, the same order of magnitude (scale), and of equal importance. Nevertheless, the vectors of hourly electricity consumption are correlated (the correlations are more powerful for closer time intervals). We calculate several more measures to check for the methodological robustness of each estimate: in other words, we check whether several evaluations lead to the same conclusions.

Let h_d and h_s be the following vectors:

$$h_d = \left(h_1^d, h_2^d, h_3^d, \ldots, h_{24}^d\right)$$

the vector of hourly electricity real consumption in the weekday d;

$$h_s = (h_1^s, h_2^s, h_3^s, \ldots, h_{24}^s)$$

the corresponding vector for weekend days s, and the components of the vectors are defined as follows:

h_t^d—is electricity real consumption for weekday d ∈ {Monday, Tuesday, Wednesday, Thursday, Friday} and time interval t, t = 1 for 0:00–0:59 interval, . . . , t = 24 for 23:00–23:59 interval.

h_t^s—is electricity real consumption for weekend day s ∈ {Saturday, or Sunday}, and time interval t, so that t = 1 for 0:00–0:59 interval, . . . , t = 24 for 23:00–23:59 interval.

For these vectors, the measures of distance (Manhattan and Mahalanobis) and similarity (the coefficient of correlation and the cosine/angle between the structure vectors) are calculated as follows:

The coefficients of correlation:	$\text{correl}(h_d, h_s) = \frac{\sum_{t=1}^{24}\left(h_t^d - \overline{h}^d\right)\left(h_t^s - \overline{h}^s\right)}{\sqrt{\sum_{t=1}^{24}\left(h_t^d - \overline{h}^d\right)^2}\sqrt{\sum_{t=1}^{24}\left(h_t^s - \overline{h}^s\right)^2}}$
The Manhattan distance (the Euclidian 1-norm):	$\text{Manhattan}(h_d, h_s) = \sum_{t=1}^{24}\left\lvert \frac{h_t^d}{\overline{h}^d} - \frac{h_t^s}{\overline{h}^s} \right\rvert$
The cosine of the angle between the structure vectors (uncentered coefficient of correlation) . . .	$\cos(h_d, h_s) = \frac{\sum_{t=1}^{24} h_t^d h_t^s}{\sqrt{\sum_{t=1}^{24}\left(h_t^d\right)^2}\sqrt{\sum_{t=1}^{24}\left(h_t^s\right)^2}}$
. . . and the angle between the structure vectors:	$\alpha_{ds} = \arccos[\cos(h_d, h_s)]$
The Mahalanobis distance	$\text{Mahalanobis}(h_d, h_s) = \sqrt{(h_d - h_s)\Sigma^{-1}(h_d - h_s)'}$

In the above formulas, $\overline{h}^d$ is the average consumption on weekday d, $\overline{h}^s$ is the average consumption on weekend day s and Σ^{-1} is the inverse of the covariance matrix.

The measures adopted in the state of emergency and alert have affected the evolution of most economic and social activities, including electricity consumption. So, we separately estimated the models for three time periods:

- Non-COVID19 time (1 January 2006–15 March 2020).
- State of emergency (16 March 2020–14 May 2020).
- State of alert (15 May 2020–8 March 2022).

We chose these intervals taking into account the fact that, based on Decree no. 195/16 March 2020 (President of Romania, 2020) [99], the state of emergency was established in the territory of Romania, starting on 16 March 2020. The state of emergency has been extended up to 14 May 2020, by Decree no. 240/14 April 2020 (President of Romania, 2020) [100]. By Law no. 55 of 15 May 2020, the state of alert was established at the national level and the measures from the state of emergency were gradually relaxed. The state of alert has been extended by government decisions given at 30-day intervals until the beginning of March 2022 (8 March 2022).

3.2. Data

In the paper, we used data regarding the electricity real consumption in Romania between 1 January 2006, and 8 March 2022 (the end date of the alert state due to COVID-19, in Romania). The data (5911 observations) come from Transelectrica statistics. According to Romanian Government Ordinance No. 627/2000,

> "Transelectrica is the Romanian Transmission and System Operator which plays a key role in the Romanian electricity market. (. . .) Transelectrica is responsible for electricity transmission, system, and market operation, grid and market infrastructure development ensuring the security of the Romanian power system. It also serves as the main link between electricity supply and demand, matching all the time power generation with demand". (https://www.transelectrica.ro/en/web/tel/despre-noi1, accessed on 23 April 2022).

Data relating to the daily reports concerning the electricity real consumption are available online on the Transelectrica website, Transparency section. They can be found either by accessing the site directly https://www.transelectrica.ro/en/web/tel/rapoarte-zilnice (from the website select "Realized Consumption"), accessed on 24 November 2022, or following this path: Transelectrica (https://www.transelectrica.ro/en/web/tel/home) → select *Transparency* → then *Balancing and Ancillary Services* → *Daily Reports* → and finally, select "Realized Consumption".

The data concerning electricity consumption (in megawatts, MW) are structured by years, months, days, and intraday, by time intervals (the data are described in the Annex). From January 2006 until January 2021, the data were presented at 24 h intervals. After February 2021, the data were available at 15 min intervals. Under these conditions, we calculated the hourly electricity real consumption by aggregation, as a simple arithmetic mean of the consumptions in the four hourly sub-intervals.

4. Results

First, we tested the hypothesis that average daily electricity real consumption (in MW) in Romania during the state of the emergency period (16 March to 14 May 2020) decreased compared to the historical average from 2006 to March 2022, and that this decrease was not due to the action of some random factors and was not just a manifestation of domain-specific seasonality. Namely, we built a model of daily electricity real consumption (ERC) dynamics with weekly (s_w = 7 days), monthly (s_m = 30 days), quarterly (s_q = 91 days), and annual (s_y = 365 days) seasonality.

In the first model, we tested the presence of a specific period effect for the interval 16 March–14 May. For this purpose, in the SAR(p)$(P_s)_s$ = w,m,q,y model, we defined the period dummy variables (*dPEREM*) as follows:

$$d_{PEREM} = a_{2018} \cdot d_{PEREM,2018} + a_{2019} \cdot d_{PEREM,2019} + a_{2020} \cdot d_{PEREM,2020} + a_{2021} \cdot d_{PEREM,2021},$$

where $d_{PEREM,t}$ is an interval dummy that takes the value 1 for each record from 16 March to 14 May, in each year t (the interval corresponds to the period during which the state of emergency was declared in 2020) and zeroes for the rest. We considered two pre-crisis years (2018 and 2019) and the two crisis years (2020–2021). If, for all the years, the coefficients of the $d_{PEREM,t}$ variables are significant and of the same sign, this means that we are in the presence of a period effect (for example, if the coefficients are significant and negative, this signals a negative seasonality: that is, the reduction in electricity consumption in spring, compared to winter, due to the reduction in electricity consumption for heating, and compared to summer, due to reduced use of cooling devices). The results are as follows:

$$\begin{aligned} ERC_t - \overline{ERC} = \; & -\underset{(-0.0060)}{1.3823} \cdot d_{PEREM_{2018}} - \underset{(-0.0739)}{15.5962} \cdot d_{PEREM_{2019}} - \underset{(-1.8124)}{192.4823} \cdot d_{PEREM_{2020}} + \underset{(0.2531)}{61.8053} \cdot d_{PEREM_{2021}} \\ & + \left[AR(1) = \underset{(174.3626)}{0.8550}\right] + \left[SAR(7) = \underset{(83.4010)}{0.6024}\right] + \left[SAR(30) = -\underset{(-4.1661)}{0.0282}\right] \\ & + \left[SAR(91) = \underset{(40.8940)}{0.3009}\right] + \left[SAR(365) = \underset{(8.0929)}{0.0505}\right] \end{aligned}$$

(below the estimators, in parentheses, are the t-Statistic values, and $\overline{ERC}$ is the mean of the daily average of electricity real consumption series).

Among the coefficients of the dummy variables, only that of the year 2020 is statistically relevant (it is significantly different from zero at the threshold of 0.035). All the other dummy variables are not significant (the probabilities attached to the null hypothesis in the unilateral Student's t-test are between 0.40 and 0.50). In addition, for the variable redundancy tests, the probability attached to the null hypothesis ($d_{PEREM,2018}$, $d_{PEREM,2019}$ and $d_{PEREM,2021}$ are jointly insignificant) is 0.9698 for the F statistic and 0.9691 for the Likelihood ratio. Instead, the coefficients of the seasonal variables are statistically relevant, at a threshold of 0.00001 or less. This means that after removing the weekly, monthly, quarterly, and annual seasonality, the model does not signal the presence of an effect specific to the period from 16 March to 14 May 2020.

To test whether there is a specific effect only during the state of emergency (16 March–14 May 2020), we respecified the previous model by removing non-significant dummy variables (corresponding to the years 2018, 2019, and 2021). The results are as follows:

$$\begin{aligned} ERC_t - \overline{ERC} = \; & \underset{(-1.8442)}{-194.82452} \cdot d_{PEREM_{2020}} + \left[AR(1) = \underset{(175.1402)}{0.85494}\right] + \left[SAR(7) = \underset{(83.3808)}{0.60244}\right] \\ & + \left[SAR(30) = \underset{(-4.1703)}{-0.02823}\right] + \left[SAR(91) = \underset{(40.9242)}{0.30096}\right] + \left[SAR(365) = \underset{(8.0973)}{0.05059}\right] \end{aligned}$$

(under the estimators, in parentheses, are the t-Statistic values; sample: 1 January 2006–8 March 2022, 5910 included observations; $R^2 = 0.909$, DW = 1.931). The coefficient of the dummy variable is significant at the 0.03 threshold, and all other parameters in the model are statistically significant at the threshold of 0.00001 or lower.

The model results support the hypothesis that, beyond seasonal effects (weekly, monthly, quarterly, yearly), the COVID-19 crisis has negatively affected electricity real consumption during the state of emergency (16 March–14 May 2020) and this decrease is not due to random factors (the coefficient attached to the dummy variable is significantly different from zero, at the 0.03 threshold) nor to the individual specific period effect (for the other years, the individual specific effects to the respective period are not statistically significant). On average, the daily electricity real consumption decreased by −194.8 MW, during the state of emergency, compared to the historical average of the period 2006–March 2022.

Concerning the second problem analysed, we mention that, for Romania, the average daily profiles of electricity real consumption (MW) on weekdays and weekend days, for the time intervals from 00:00–00:59 to 23:00–23:59, during the state of emergency (16 March

2020–14 May 2020) and the state of the alert period, compared to time without COVID-19 (1 January 2006–15 March 2020) are shown in Figures 1 and 2.

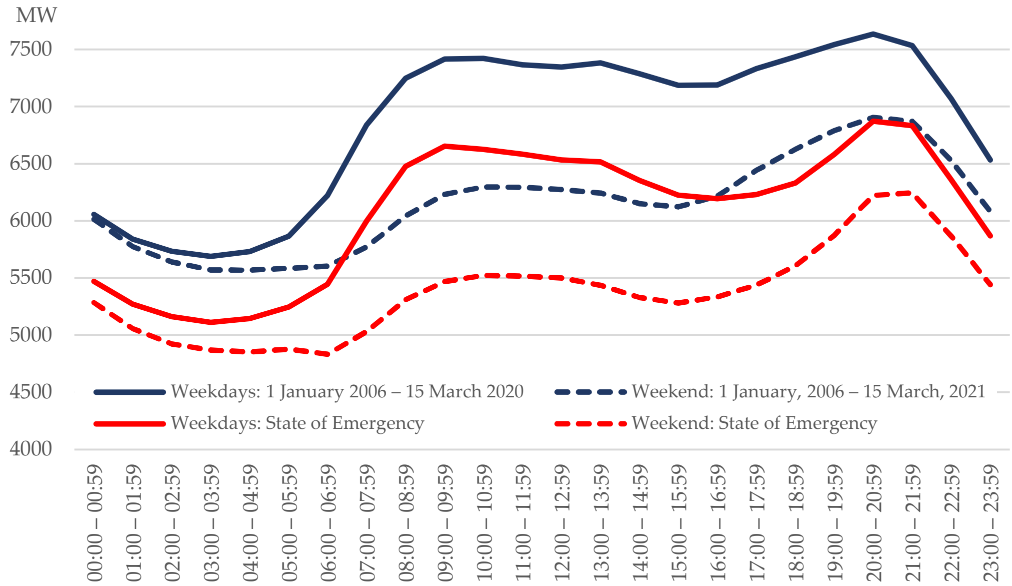

Figure 1. Average daily profiles of electricity real consumption (MW), in Romania, during the state of emergency (16 March 2020–14 May 2020) compared to non-COVID-19 time (1 January 2006–15 March 2020). Source: authors' estimations based on hourly electricity real consumption data (MW) from Transelectrica, starting with January 2006, until 8 March 2022 (the end date of the alert state due to COVID-19, in Romania).

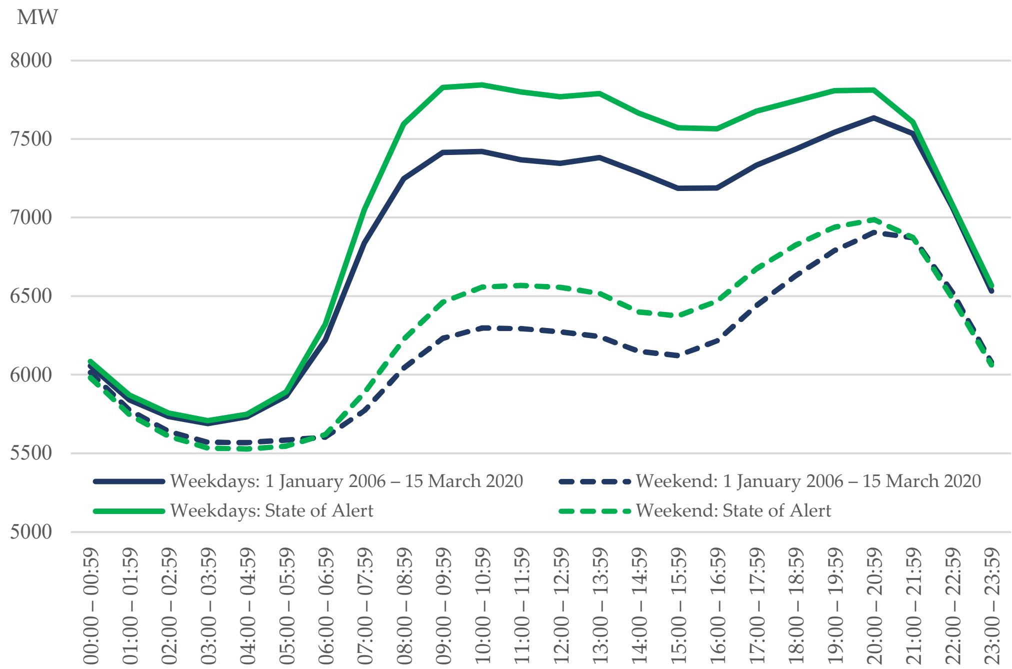

Figure 2. Average daily profiles of electricity real consumption (MW) in Romania, during the state of alert (15 May 2020–8 March 2022), compared to non-COVID-19 time (1 January 2006–15 March 2020). Source: authors' estimations based on hourly electricity real consumption data (MW) from Transelectrica, starting with January 2006, until 8 March 2022 (the end date of the alert state due to COVID-19, in Romania).

The average electricity real consumption during the state of emergency (the blue line, for weekdays, and the dashed blue line for weekend days in Figure 1) is under the corresponding consumption during the pre-crisis periods (the red lines in Figure 1). This means that both aggregated and in each time interval, the impact of the COVID-19 crisis on electricity consumption was negative. These developments are consistent with those recorded in most states around the world during the first phase of the COVID-19 crisis, developments recorded as such in the literature: e.g., International Energy Agency (2020) [63] for the countries of the world; Bahmanyar, Estebsari, and Ernst (2020) [71] for Europe; Armeanu, Joldeș and Gherghina (2022) [61] for Romania, and so on.

The weekdays' average electricity real consumption profile during the state of emergency (the red line in Figure 1) is close to the weekend days profile of non-COVID-19 time (the dashed blue line in Figure 1). This finding is consistent with the *International Energy Agency* hypothesis: "the pattern on weekdays now resembles the pattern usually seen only on Sundays" (International Energy Agency, 2020, p. 23) [63].

During the state of alert (15 May 2020–8 March 2022), the electricity real consumption (the green lines in Figure 2) in Romania is higher than the consumption in the non-COVID-19 period (1 January 2006–15 March 2020, the blue lines in Figure 2) and the daily profiles are similar both for weekdays and for weekend days. This means that the decrease in total electricity real consumption during the state of emergency was relatively quickly recovered in the state of alert period. From 7 a.m. to 10 p.m., in each hourly interval, the average electricity real consumption was greater in the state of the alert period than in the pre-crisis period. Throughout the night, consumption behaviour during the state of alert period returned to the pre-crisis profile.

To go beyond the simple interpretation of the graphs, we calculated the distance and similarity measures between the daily vectors of electricity consumption (each with 24 components).

First, we used data for 24 h time intervals (0:00 a.m. to 11:59 p.m.) and computed the coefficient of correlation, as a similarity measure between hourly electricity real consumption during the weekdays and the corresponding consumption on weekend days. We found that the values calculated for *the state of the emergency* period (16 March 2020–14 May 2020) are slightly higher than the historical average (1 January 2006–15 March 2020), concretely 0.8622 compared to 0.8522. By days, the correlations are slightly higher in the state of emergency compared to the multiannual averages on Monday, Tuesday, and Friday, and as average Monday–Friday, and they are slightly lower on Wednesday and Thursday (Table 1).

Table 1. Distance between the hourly electricity real consumption during the weekdays and the corresponding consumption of weekend days for all time intervals.

Time Interval: All-Day	Monday	Tuesday	Wednesday	Thursday	Friday	Average Monday–Friday
	The coefficient of correlation (values between −1 and +1, values closer to 1 representing stronger positive correlation)					
1 January 2006–15 March 2020	0.8484	0.8514	0.8546	0.8522	0.8522	0.8522
16 March 2020–14 May 2020	0.8580	0.8519	0.8533	0.8410	0.8973	0.8622
15 May 2020–8 March 2022	0.7975	0.7877	0.7933	0.7892	0.7837	0.7913
	The Manhattan distance (a smaller Manhattan distance suggests that two distributions are more statistically similar to each other)					
1 January 2006–15 March 2020	1.5555	1.1289	1.0949	1.0831	1.0326	1.1645
16 March 2020–14 May 2020	1.4164	1.1780	1.0551	1.0114	0.6958	1.0639
15 May 2020–8 March 2022	2.0191	1.6239	1.5760	1.5299	1.4631	1.6340
	The angle between the vectors of the structures (values between 0 and 90 degrees; the smaller the value, the closer the structures are)					
1 January 2006–15 March 2020	4.3267°	3.0447°	2.9461°	2.8986°	2.7209°	3.1520°
16 March 2020–14 May 2020	3.9923°	3.1937°	2.8807°	2.7631°	1.9342°	2.8882°
15 May 2020–8 March 2022	5.4179°	4.2204°	4.0987°	3.9620°	3.7608°	4.2616°

Source: authors' estimations based on hourly electricity real consumption data (MW) from Transelectrica, starting with January 2006, until 8 March 2022 (the end date of the alert state due to COVID-19 in Romania).

If we compare the difference (dissimilarity) between the structural vectors of hourly consumption, through the Manhattan distance and the angle between the vectors, the conclusions are similar: the differences registered during the state of emergency on weekdays are slightly lower compared to the historical averages for weekend days, i.e., 1.0639 for 1.1645 (Manhattan distance), respectively, 2.8882 for 3.1520 (angle between vectors). The coefficients of correlation calculated for the state of the alert period (15 May 2020–8 March 2022) are higher than in the state of emergency, but the differences are not large in absolute values. The Manhattan distances and the angles between the structural vectors are closer to the historical averages than to the indices calculated for the period of the state of emergency. This means a gradual return to pre-COVID-19 crisis consumer behaviour.

The three indicators (coefficient of correlation—for similarity, Manhattan distance, and angle between vectors for dissimilarity), computed for each day of the week, are shown in Table 1 and Figures 3–5.

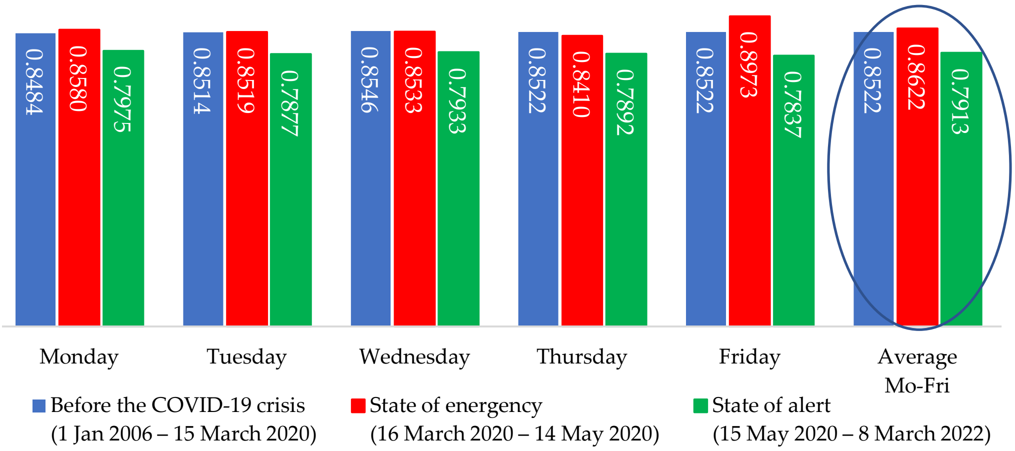

Figure 3. Coefficients of correlation between the hourly electricity real consumption during the weekdays and the typical corresponding profile consumption of weekend days. Note 1: Coefficient of correlation measures the similarity between two objects, values are between −1 and +1, values closer to 1 representing stronger positive correlation. Note 2: Values for the coefficients of correlation differ among the days of the week. We marked the weekly average values (Monday to Friday) with the blue ellipse. Source: Table 1.

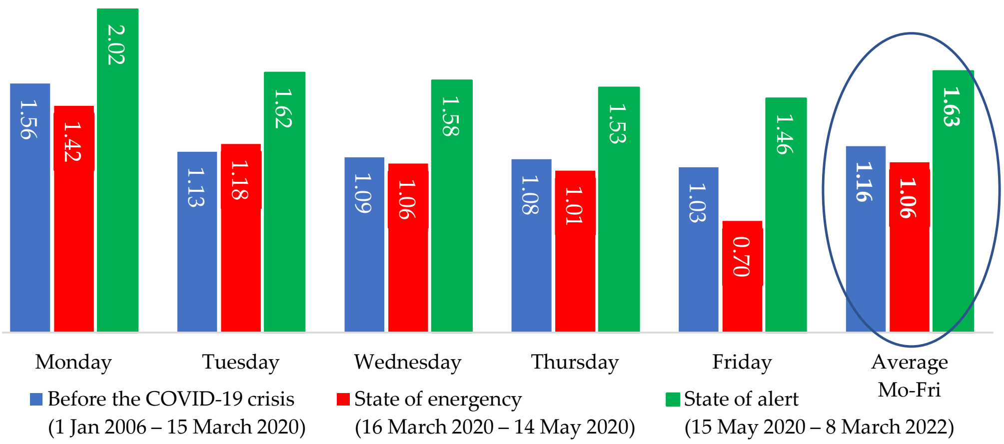

Figure 4. Manhattan distances between the hourly electricity real consumption during the weekdays and the typical corresponding profile consumption of weekend days. Note 1: A smaller Manhattan distance suggests that two distributions are more statistically similar to each other. Note 2: Values for the Manhattan distance differ among the days of the week. We marked with the blue ellipse the weekly average values (Monday to Friday). Source: Table 1.

Technically, the values compared to the average of the weekends are between those of Saturday (the greatest similarity) and Sunday (the greatest dissimilarity).

For the state of alert, the correlations are weaker, and the dissimilarities are higher than in the state of emergency and they are closer to the values recorded in the period before the outbreak of the COVID-19 pandemic.

Another interesting finding for Romanian electricity real consumption is that the hourly consumption profile on weekdays, during the state of emergency, is closer to the specific structure of Saturday than Sunday (Table 2).

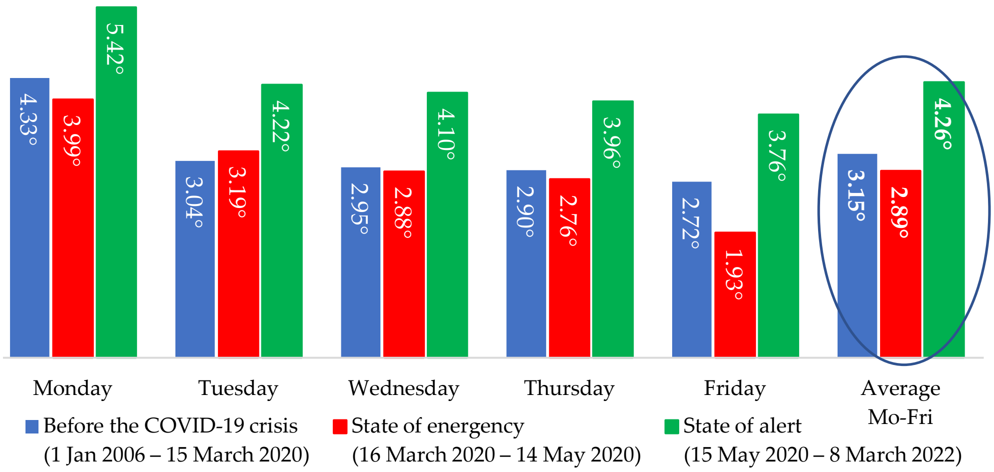

Figure 5. The angle between the vectors of the structures (degrees) between the hourly electricity real consumption during the weekdays and the typical corresponding profile consumption of weekend days. Note 1: Values between 0 and 90 degrees; the smaller the value, the closer the structures. Note 2: Values differ among the days of the week. We marked the weekly average values (Monday to Friday) with the blue ellipse. Source: Table 1.

Table 2. Distance between the hourly electricity real consumption in a state of emergency during the weekdays and the profile of consumption corresponding to Saturday, Sunday, and the average of the weekend days, respectively.

The Weekdays' Consummation in a State of Emergency Compared to:	Monday	Tuesday	Wednesday	Thursday	Friday	Average Monday–Friday
	The coefficient of correlation (values between −1 and +1, values closer to 1 representing stronger positive correlation)					
Average of weekend days	0.8580	0.8519	0.8533	0.8410	0.8973	0.8622
Saturday	0.9311	0.9307	0.9297	0.9198	0.9472	0.9349
Sunday	0.7368	0.7249	0.7288	0.7144	0.8001	0.7413
	The Manhattan distance (a smaller Manhattan distance suggests that two distributions are more statistically similar to each other)					
Average of weekend days	1.4164	1.1780	1.0551	1.0114	0.6958	1.0639
Saturday	1.2351	0.9431	0.8266	0.7742	0.4974	0.8343
Sunday	1.6689	1.4764	1.3609	1.3234	0.9663	1.3516
	The angle between the vectors of the structures (values between 0 and 90 degrees; the smaller the value, the closer the structures are)					
Average of weekend days	3.9923	3.1937	2.8807	2.7631	1.9342	2.8882
Saturday	3.4171	2.5435	2.2329	2.1138	1.4248	2.2576
Sunday	4.6825	3.9508	3.6404	3.5256	2.6366	3.6362

Source: authors' estimations based on hourly electricity real consumption data (MW) from Transelectrica, starting with January 2006 until March 8, 2022 (the end date of the alert state due to COVID-19 in Romania).

We also estimated the Mahalanobis distances (Table 3) between the vectors of hourly electricity real consumption during the pandemic period and the corresponding vectors in normal (pre-pandemic) times.

The Mahalanobis distances between the actual electricity consumption per hourly step, on average over weekdays, and the corresponding consumption on weekend days are lower for the state of emergency period. In addition, the distances between the weekday consumption profile of the emergency period and the consumption profile of the pre-crisis weekends (3.57) are smaller than the distances between the profiles corresponding to the days of pre-crisis weekdays and weekend days (4.14). During the state of alert, the hourly patterns of real electricity consumption returned to the normal profile (observed before the crisis).

Table 3. Mahalanobis distances between the hourly electricity real consumptions on weekdays and corresponding consumptions on weekend days.

			Mahalanobis Distances	
Average weekdays' hourly profile of electricity real consumption in:	pre-crisis period	and Saturday	in pre-crisis period	4.33
		and Sunday		4.05
		and weekend average		4.14
	state of emergency period	and Saturday	in pre-crisis period	3.73
		and Sunday		3.52
		and weekend average		3.57
		and Saturday	in a state of emergency period	2.77
		and Sunday		3.10
		and weekend average		2.85
	state of the alert period	and Saturday	in pre-crisis period	4.35
		and Sunday		4.12
		and weekend average		4.19
		and Saturday	in the state of the alert period	4.55
		and Sunday		3.61
		and weekend average		3.99

Note: A smaller Mahalanobis distance suggests that two distributions are more statistically similar to each other. Source: Author's estimations based on hourly electricity real consumption data (MW) from Transelectrica, starting with January 2006 until 8 March 2022 (the end date of the alert state due to COVID-19 in Romania).

5. Conclusions

The COVID-19 crisis and the measures against the spread of the pandemic—the lockdown measures, work from home, online education, blocking of tourist and leisure activities, of sports and cultural activities, closure of theatres, movie theatres, restaurants, bars, and nightclubs, restriction of commercial activities in stores, and so on—have severely affected economic and social activities, which has had negative effects on electricity supply and consumption.

In the paper, we analysed the changes in electricity consumption generated by COVID-19 and the measures taken against the spread of the coronavirus to limit the effects of the pandemic. We found that on average, the daily electricity real consumption decreased by −194.8 MW during the state of emergency compared to the historical average of the period 2006–March 2022. The dimension of the COVID-19 impact represents approximately −2.84%, compared to the average of the actual electricity consumption of 2019 (6858.7 MW) and −2.94%, compared to the related period from 2019.

For comparison, Soava et al. (2021) [101], found that, in the first 11 months of 2020, total energy consumption decreased by approx. 4%. According to Eurostat data (table nrg_cb_e), total electricity final consumption in Romania fell by −3.1% in 2020 (−3.9 for EU27, and −4.4% for the Euro area), and recovered in 2021 (+5.4%), slightly faster than in the EU27 and Euro area (+4.5%).

The literature has analysed the structural changes generated by the decline in commercial electricity consumption, which were partially compensated by the increase in household consumption (Jula D.-M., 2021) [102].

Based on this finding, it was hypothesised that the profile of daily electricity consumption on weekdays is close to the typical Sunday profile (International Energy Agency, 2020 [63]; Burleyson et al., 2020 [68]; Goddard, 2020 [69]; Staffell, 2020 [64]; Wilson et al., 2020 [67]; Mehlig et al., 2021 [66]). In general, this is a conclusion based on logical deductions and the analysis of some graphs.

To go beyond the simple interpretation of the graphs, for Romania, we calculated some measures of distance and similarity between the daily vectors of electricity real consumption (each with 24 hourly components). To assess the degree of similarity/dissimilarity between the pattern of hourly electricity real consumption on the weekdays and the corresponding vector for weekend days, we calculated the linear correlation coefficient and the angle between the structure vectors (for similarity evaluation), the Manhattan distance and the

Mahalanobis distance (for dissimilarity estimation). The standard consumption structures were calculated as averages for the period until 1 January 2006, to 15 March 2020.

We separately estimated the models for three time periods: before the COVID-19 outbreak (1 January 2006–15 March 2020), the state of the emergency episode (16 March 2020–14 May 2020), and the state of the alert period (15 May 2020–8 March 2022).

Concerning the profile of weekdays' electricity consumption, we found some pieces of evidence of the Saturday effect for Romania, only for the state of emergency period and not for the state of alert period. During the state of alert, consumption returns to the pre-crisis profile.

That is, for Romania, in terms of electricity consumption, "under lockdown, every day is a Sunday" of Staffell (2020, p. 4) [64], it is rather "under lockdown, every day is (almost) a Saturday"! Additionally, this effect is not extraordinarily strong. This is because (Liasi, Shahbazian, & Bina, 2020 [65]) there are activities which, in normal times, were carried out on weekends, which stopped (e.g., shows, tourism) or slowed down (e.g., direct purchases in stores) during lockdown. Additionally, some activities were not stopped during the pandemic (for example, activities that do not involve direct interaction between people, or medical activities).

Habitually, the evaluation of Mahalanobis distances would have been sufficient to support the paper's conclusions. However, the value obtained for the determinant of the covariance matrix Σ was very large, which could have generated, mathematically, a certain inaccuracy in the calculation of the inverse (Σ^{-1}). For safety (and methodological robustness), we estimated and used analysis indicators from different classes. All the quantitative estimates converge toward the same conclusions mentioned above.

A limitation of the study is that it does not provide quantitative assessments of cause–effect relationships, by factors. The effects of the crisis on changes in energy consumption behaviour by days and hours are measured, but the consequences by types of actions (individual factors) are not measured (e.g., the direct effect of school closures on household electricity consumption, the direct effect of working from home, the effect of illnesses and hospitalisations). The paper only measures the overall result.

These elements open several paths for future research. An interesting direction of study is the establishment of methodological benchmarks for analysing electricity consumption in universities during the pandemic and estimating consumption in the households the students come from. The main methodological difficulties refer to the identification of solutions to separate the effects on electricity consumption induced by students' online learning from other factors that occur at the same time (for example, work from home for parents or other family members, the effects of the school closures for younger siblings, etc.). Such an analysis could have interesting policy implications from the perspective of expanding and diversifying forms of online learning.

Our present study could have useful policy implications, especially for energy policy, not only from the perspective of the emergence of similar crises but also starting from the (plausible) hypothesis that certain processes that emerged in the context of the pandemic crisis will tend to be maintained in the medium and long term: a preference for working from home, maintaining and developing some forms of online learning, increasing and diversifying the online commerce, maintaining certain forms of social distancing, etc.

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Data Availability Statement: Transelectrica website, Transparency section (Transelectrica is the Romanian Transmission and System Operator in the Romanian electricity market). In addition to direct access to data, by accessing the site (https://www.transelectrica.ro/en/web/tel/rapoarte-zilnice (from the website select "Realized Consumption"), accessed on 24 November 2022, we enclosed an alternative access path: Transelectrica (https://www.transelectrica.ro/en/web/tel/home) → select Transparency → then Balancing and Ancillary Services → Daily Reports → and finally, select "Realized Consumption".

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

References

1. Glennerster, R.; Snyder, C.M.; Tan, B.J. *Calculating the Costs and Benefits of Advance Preparations for Future Pandemics*; Working Paper 30565; National Bureau of Economic Research (NBER): Cambridge, MA, USA, 2022. [CrossRef]
2. National Institute of Statistics. National Accounts. Quarterly Gross Domestic Product (Tables CON104J and CON104N). 2022. Available online: http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table (accessed on 6 May 2022).
3. National Institute of Statistics. Energy. Energy Balances by Component Elements (Table IND108A). 2022. Available online: http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table (accessed on 6 May 2022).
4. The Economist. Tracking COVID-19 Excess Deaths Across Countries. Available online: https://www.economist.com/graphic-detail/coronavirus-excess-deaths-tracker (accessed on 28 November 2022).
5. Biederman, I. Recognition-by-components: A Theory of human image understanding. *Psychol. Rev.* **1987**, *94*, 115–147. [CrossRef] [PubMed]
6. Da Fontoura Costa, L.; Cesar, R.M. *Shape Analysis and Classification: Theory and Practice*; CRC Press: Boca Raton, FL, USA, 2000.
7. Batley, S. *Classification in Theory and Practice*, 2nd ed.; Elsevier: Amsterdam, The Netherlands, 2015. [CrossRef]
8. Parrochia, D. *Classification*; Fieser, J., Dowden, B., Eds.; The Internet Encyclopedia of Philosophy: USA, 2016. Available online: https://iep.utm.edu/classification-in-science/ (accessed on 5 November 2022).
9. Bishop, C.M. *Pattern Recognition and Machine Learning*; Springer: Berlin/Heidelberg, Germany, 2007.
10. Banoula, M. Classification in Machine Learning: What It Is and Classification Models. AI & Machine Learning. Available online: https://www.simplilearn.com/tutorials/machine-learning-tutorial/classification-in-machine-learning (accessed on 25 November 2022).
11. Yang, T.; Gerasoulis, A. Web Search Engines: Practice and Experience. In *Computer Handbook: Computer Science and Software Engineering*, 3rd ed.; Tucker, A., Gonzalez, T., Topi, H., Diaz-Herrera, J., Eds.; Taylor and Francis Group/CRC Press: Boca Raton, FL, USA, 2014; p. 24. Available online: https://sites.cs.ucsb.edu/~tyang/papers/bookchaptersearch.pdf (accessed on 5 November 2022).
12. Kameni Homte, J.S.; Batchakui, B.; Nkambou, R. Search Engines in Learning Contexts: A Literature Review. *Int. J. Emerg. Technol. Learn.* **2022**, *17*, 254–272. [CrossRef]
13. Han, J.; Kamber, M.; Pei, J. *Data Mining: Concepts and Techniques*, 3rd ed.; Elsevier: Amsterdam, The Netherlands, 2012.
14. Tan, P.-N.; Steinbach, M.; Karpatne, A.; Kumar, V. *Introduction to Data Mining*, 2nd ed.; Pearson: London, UK, 2018.
15. Hjørland, B.; Pedersen, K.N. A substantive theory of classification for information retrieval. *J. Doc.* **2005**, *61*, 582–597. [CrossRef]
16. Russell, S.; Norvig, P. *Artificial Intelligence: A Modern Approach*, 4th ed.; Pearson: London, UK, 2020.
17. Manyika, J. Getting AI Right: Introductory Notes on AI & Society. *Daedalus* **2022**, *151*, 5–27. [CrossRef]
18. Nicola, M.; Alsafi, Z.; Sohrabi, C.; Kerwan, A.; Al-Jabir, A.; Iosifidis, C.; Agha, R. The socio-economic implications of the coronavirus pandemic (COVID-19): A review. *Int. J. Surg.* **2020**, *78*, 185–193. [CrossRef]
19. Alshater, M.M.; Atayah, O.F.; Khan, A. What do we know about business and economics research during COVID-19: A bibliometric review. *Econ. Res.* **2021**, *29*, 1884–1912. [CrossRef]
20. Brodeur, A.; Gray, D.; Islam, A.; Suraiya, B. A literature review of the economics of COVID-19. *J. Econ. Surv.* **2021**, *35*, 1007–1044. [CrossRef]
21. Callegari, B.; Feder, C. A Literature Review of Pandemics and Development: The Long-Term Perspective. *Econ. Disasters Clim. Chang.* **2022**, *6*, 183–212. [CrossRef]
22. Podolsky, M.I.; Present, I.; Neumann, P.J.; Kim, D.D. A Systematic Review of Economic Evaluations of COVID-19 Interventions: Considerations of Non-health Impacts and Distributional Issues. *Value Health* **2022**, *25*, 1298–1306. [CrossRef]
23. de Oliveira Coutinho, C.; Mota, T.M.L.; Santos, L.P.; da Silva, T.S.; Conde, T.N.; Mulder, A.D.R.P.; Seixas, C.M. The impact of the COVID-19 pandemic on eating disorders and their treatment: An integrative literature review. *Res. Soc. Dev.* **2021**, *10*, 14. [CrossRef]
24. Şevgin, Ö.; Alptekin, H.K.; Şevgin, K. The Weak Ring of the COVID-19 Pandemic: The Elderly (A Literature Review). *Geriatr. Med. Gerontol.* **2021**, *7*, 7. [CrossRef]
25. Rana, R.H.; Keramat, S.A.; Gow, J. A Systematic Literature Review of the Impact of COVID-19 Lockdowns on Air Quality in China. *Aerosol Air Qual. Res.* **2021**, *21*, 20. [CrossRef]
26. Khlystova, O.; Kalyuzhnova, Y.; Belitski, M. The impact of the COVID-19 pandemic on the creative industries: A literature review and future research agenda. *J. Bus. Res.* **2022**, *139*, 1192–1210. [CrossRef] [PubMed]

27. Haafza, L.A.; Awan, M.J.; Abid, A.; Yasin, A.; Nobanee, H.; Farooq, M.S. Big Data COVID-19 Systematic Literature Review: Pandemic Crisis. *Electronics* **2021**, *10*, 3125. [CrossRef]
28. Gunasekeran, D.V.; Chew, A.; Chandrasekar, E.K.; Rajendram, P.; Kandarpa, V.; Rajendram, M.; Chia, A.; Smith, H.; Leong, C.K. The Impact and Applications of Social Media Platforms for Public Health Responses before and during the COVID-19 Pandemic: Systematic Literature Review. *J. Med. Internet Res.* **2022**, *24*, e33680. [CrossRef]
29. Cachón-Zagalaz, J.; Sánchez-Zafra, M.; Sanabrias-Moreno, D.; González-Valero, G.; Lara-Sánchez, A.J.; Zagalaz-Sánchez, M.L. Systematic Review of the Literature About the Effects of the COVID-19 Pandemic on the Lives of School Children. *Front. Psychol.* **2020**, *11*, 569348. [CrossRef]
30. Marinoni, G.; van't Land, H.; Jensen, T. *The Impact of COVID-19 on Higher Education around the World*; IAU Global Survey Report 23; International Association of Universities: Paris, France, 2020; Available online: https://www.iau-aiu.net/IMG/pdf/iau_covid19_and_he_survey_report_final_may_2020.pdf (accessed on 18 April 2022).
31. Pokhrel, S.; Chhetri, R. A Literature Review on Impact of COVID-19 Pandemic on Teaching and Learning. *High. Educ. Future* **2021**, *8*, 133–141. [CrossRef]
32. Shan, X.; Beheshti, M. Literature Review of COVID-19 Pandemic Impacts on Students Academic Performance. In Proceedings of the 6th International Conference on Distance Education and Learning, Shanghai, China, 21–24 May 2021; Association for Computing Machinery: New York, NY, USA, 2021; pp. 233–237. [CrossRef]
33. Zancajo, A. *The Impact of the COVID-19 Pandemic on Education. Rapid Review of the Literature*; COVID and Societ—British Academy, University of Glasgow, School of Education: London, UK, 2021. Available online: https://www.thebritishacademy.ac.uk/documents/3226/COVID-decade-The-impact-on-education-Rapid-review-Adrian-Zancajo-Glasgow.pdf (accessed on 22 April 2022).
34. Alifuddin, N.A.; Ibrahim, D. Studies on the Impact of Work from Home During COVID-19 Pandemic: A Systematic Literature Review. *J. Komun. Borneo* **2021**, *9*, 60–80. [CrossRef]
35. Štreimikienė, D.; Baležentis, T.; Volkov, A.; Ribašauskienė, E.; Morkūnas, M.; Žičkienė, A. Negative effects of COVID-19 pandemic on agriculture: Systematic literature review in the frameworks of vulnerability, resilience and risks involved. *Econ. Res.* **2021**, *35*, 529–545. [CrossRef]
36. Herby, J.; Jonung, L.; Hanke, S.H. A Literature Review and Meta-Analysis of the Effects of Lockdowns on COVID-19 Mortality. (G. H. The Johns Hopkins Institute for Applied Economics, Ed.) Studies in Applied Economics, 200, 61p. Available online: https://sites.krieger.jhu.edu/iae/files/2022/01/A-Literature-Review-and-Meta-Analysis-of-the-Effects-of-Lockdowns-on-COVID-19-Mortality.pdf (accessed on 20 April 2022).
37. Agyei, S.K.; Bossman, A.; Asafo-Adjei, E.; Asiamah, O.; Adela, V.; Adorm-Takyi, C. Exchange Rate, COVID-19, and Stock Returns in Africa. *Discret. Dyn. Nat. Soc.* **2022**, *20*, 4372808. [CrossRef]
38. Sun, L.; Shi, W. Investor Sentiment and Stock Market Reactions to COVID-19: Evidence from China. *Discret. Dyn. Nat. Soc.* **2022**, *10*, 8413916. [CrossRef]
39. Owusu Junior, P. Dynamic Connectedness, Spillovers, and Delayed Contagion between Islamic and Conventional Bond Markets: Time- and Frequency-Domain Approach in COVID-19 Era. *Discret. Dyn. Nat. Soc.* **2022**, *18*, 1606314. [CrossRef]
40. Wang, Q.; Huang, R.; Li, R. Towards smart energy systems—A survey about the impact of COVID-19 pandemic. *Energy Strategy Rev.* **2022**, *41*, 100845. [CrossRef]
41. Chong, C.T.; Fan, Y.V.; Lee, C.T.; Klemeš, J.J. Post COVID-19 ENERGY sustainability and carbon emissions neutrality. *Energy* **2022**, *241*, 122801. [CrossRef] [PubMed]
42. Radtke, J. Smart energy systems beyond the age of COVID-19: Towards a new order of monitoring, disciplining and sanctioning energy behavior? *Energy Res. Soc. Sci.* **2022**, *84*, 15. [CrossRef] [PubMed]
43. Dogan, E.; Majeed, M.T.; Luni, T. Analyzing the nexus of COVID-19 and natural resources and commodities: Evidence from time-varying causality. *Resour. Policy* **2022**, *77*, 14. [CrossRef]
44. Salisu, A.; Adediran, I. Uncertainty due to infectious diseases and energy market volatility. *Energy Res. Lett.* **2020**, *1*, 6. [CrossRef]
45. Pastory, D.; Munishi, E. Volatility Shocks in Energy Commodities: The Influence of COVID-19. *Int. J. Res. Bus. Soc. Sci.* **2022**, *11*, 214–227. [CrossRef]
46. Shaikh, I. Impact of COVID-19 pandemic on the energy markets. *Econ. Chang. Restruct.* **2022**, *55*, 433–484. [CrossRef]
47. Lazo, J.; Aguirre, G.; Watts, D. An impact study of COVID-19 on the electricity sector: A comprehensive literature review and Ibero-American survey. *Renew. Sustain. Energy Rev.* **2022**, *158*, 15. [CrossRef]
48. Cicala, S. *Powering Work from Home*; Working Paper 27937; National Bureau of Economic Research (NBER): Cambridge, MA, USA, 2022. [CrossRef]
49. Wang, J.; Li, F.; Cui, H.; Shi, Q.; Mingee, T. Electricity consumption variation versus economic structure during COVID-19 on metropolitan statistical areas in the US. *Nat. Commun.* **2022**, *13*, 11. [CrossRef] [PubMed]
50. Li, Z.; Ye, H.; Liao, N.; Wang, R.; Qiu, Y.; Wang, Y. Impact of COVID-19 on electricity energy consumption: A quantitative analysis on electricity. *Int. J. Electr. Power Energy Syst.* **2022**, *140*, 16. [CrossRef]
51. García, S.; Parejo, A.; Personal, E.; Guerrero, J.I.; Biscarri, F.; León, C. A retrospective analysis of the impact of the COVID-19 restrictions on energy consumption at a disaggregated level. *Appl. Energy* **2021**, *193*, 84–95. [CrossRef] [PubMed]
52. Cortiços, N.D.; Duarte, C.C. Energy efficiency in large office buildings post-COVID-19 in Europe's top five economies. *Energy Sustain. Dev.* **2022**, *68*, 410–424. [CrossRef] [PubMed]

53. Su, Y.; Cheng, H.; Wang, Z.; Wang, L. Impacts of the COVID-19 lockdown on building energy consumption and indoor environment: A case study in Dalian, China. *Energy Build.* **2022**, *263*, 18. [CrossRef]
54. Todeschi, V.; Javanroodi, K.; Castello, R.; Mohajeri, N.; Mutani, G.; Scartezzini, J.-L. Impact of the COVID-19 pandemic on the energy performance of residential neighborhoods and their occupancy behavior. *Sustain. Cities Soc.* **2022**, *82*, 19. [CrossRef]
55. Balest, J.; Stawinoga, A.E. Social practices and energy use at home during the first Italian lockdown due to COVID-19. *Sustain. Cities Soc.* **2022**, *78*, 13. [CrossRef]
56. Buechler, E.; Powell, S.; Sun, T.; Astier, N.; Zanocco, C.; Bolorinos, J.; Rajagopal, R. Global changes in electricity consumption during COVID-19. *iScience* **2022**, *25*, 103568. [CrossRef]
57. Moses, C.I. Speed and Surprises: Decline and Recovery of Global Electricity Use in COVID's First Seven Months. 2022. Available online: https://news.stanford.edu/2022/02/11/fall-rise-electricity-use-early-pandemic/ (accessed on 11 February 2022).
58. He, Y.; Zhang, Z. Energy and Economic Effects of the COVID-19 Pandemic. *Sustainability* **2022**, *14*, 12043. [CrossRef]
59. Narajewski, M.; Ziel, F. Changes in electricity demand pattern in Europe due to COVID-19 shutdowns. *arXiv* **2020**, arXiv:2004.14864. Available online: https://arxiv.org/pdf/2004.14864.pdf (accessed on 6 May 2022).
60. Zhang, L.; Li, H.; Lee, W.-J.; Liao, H. COVID-19 and energy: Influence mechanisms and research methodologies. *Sustain. Prod. Consum.* **2021**, *27*, 2134–2152. [CrossRef] [PubMed]
61. Armeanu, D.-Ș.; Joldeș, C.-C.; Gherghina, Ș.-C. How Energy Sector Reacted to COVID-19 Pandemic? Empirical Evidence from an Emerging Market Economy. *Discret. Dyn. Nat. Soc.* **2022**, *26*, 3380183. [CrossRef]
62. Andrei, P.C.; Stănculescu, M.; Andrei, H.; Căciulă, I.; Diaconu, E.; Bizon, N.; Găiceanu, M. Comparative and Predictive Analysis of Electrical Consumption during pre- and Pandemic Periods: Case Study for Romanian Universities. *Sustainability* **2022**, *14*, 11346. [CrossRef]
63. International Energy Agency. *Global Energy Review 2020. The Impacts of the COVID-19 Crisis on Global Energy Demand and CO_2 Emissions*; IEA Publications; International Energy Agency: Paris, France, 2020. Available online: https://iea.blob.core.windows.net/assets/7e802f6a-0b30-4714-abb1-46f21a7a9530/Global_Energy_Review_2020.pdf (accessed on 15 December 2021).
64. Staffell, I. *Under Lockdown, Every Day is a Sunday. Drax Electric Insights Quarterly*; Imperial College London: London, UK, 2020. Available online: https://www.drax.com/opinion/under-lockdown-every-day-is-a-sunday/ (accessed on 29 April 2022).
65. Liasi, S.G.; Shahbazian, A.; Bina, M.T. COVID-19 Pandemic; Challenges and Opportunities in Power Systems. (I. o. (IEEE), Ed.). 2020. Available online: https://smartgrid.ieee.org/bulletins/may-2020/covid-19-pandemic-challenges-and-opportunities-in-power-systems (accessed on 6 May 2022).
66. Mehlig, D.; ApSimon, H.; Staffel, I. The impact of the UK's COVID-19 lockdowns on energy demand and emissions. *Environ. Res. Lett.* **2021**, *16*, 10. [CrossRef]
67. Wilson, G.; Godfrey, N.; Sharma, S.; Bassett, T. We Analysed Electricity Demand and Found Coronavirus has Turned Weekdays into Weekends. The Conversation. 31 March 2020. Available online: https://theconversation.com/we-analysed-electricity-demand-and-found-coronavirus-has-turned-weekdays-into-weekends-134606 (accessed on 1 May 2022).
68. Burleyson, C.D.; Smith, A.; Rice, J.S.; Voisin, N.; Rahman, A. *Changes in Electricity Load Profiles under COVID-19: Implications of "The New Normal" for Electricity Demand*; Open Engineering Inc., Ed.: Menomonie, WI, USA, 2020. [CrossRef]
69. Goddard, I. National Lockdown Effects on European Electricity Consumption and System Planning. (I. Home, Ed.). 31 March 2020. Available online: https://invenia.github.io/blog/2020/03/31/covid-part1/ (accessed on 1 May 2022).
70. Burleyson, C.D.; Rahman, A.; Rice, J.S.; Smith, A.D.; Voisin, N. Multiscale Effects Masked the Impact of the COVID-19 Pandemic on Electricity Demand in the United States. *Appl. Energy* **2021**, *304*, 10. [CrossRef]
71. Bahmanyar, A.; Estebsari, A.; Ernst, D. The impact of different COVID-19 containment measures on electricity consumption in Europe. *Energy Res. Soc. Sci.* **2020**, *68*, 4. [CrossRef]
72. Santiago, I.; Moreno-Munoz, A.; Quintero-Jiménez, P.; Garcia-Torres, F.; Gonzalez-Redondo, M.J. Electricity demand during pandemic times: The case of the COVID-19 in Spain. *Energy Policy* **2021**, *148*, 17. [CrossRef]
73. Abdeen, A.; Kharvari, F.; O'Brien, W.; Gunay, B. The impact of the COVID-19 on households' hourly electricity consumption in Canada. *Energy Build.* **2021**, *250*, 17. [CrossRef]
74. Rouleau, J.; Gosselin, L. Impacts of the COVID-19 lockdown on energy consumption in a Canadian social housing building. *Appl. Energy* **2021**, *287*, 11. [CrossRef]
75. Hinson, S. COVID-19 Is Changing Residential Electricity Demand. 10 April 2020. Available online: https://www.tdworld.com/distributed-energy-resources/demand-side-management/article/21128542/covid19-is-changing-residential-electricity-demand (accessed on 6 May 2022).
76. Krarti, M.; Aldubyan, M. Review analysis of COVID-19 impact on electricity demand for residential buildings. *Renew. Sustain. Energy Rev.* **2021**, *143*, 13. [CrossRef]
77. Brewer, D. Changes in Electricity Use Following COVID-19 Stay-at-Home Behavior. 1 November 2022. Available online: https://www.dylanbrewer.com/wp-content/uploads/2021/01/Brewer_electricityuse_covid19_20210721.pdf (accessed on 5 November 2022).
78. Ku, A.; Qiu, Y.; Lou, J.; Nock, D.; Xing, B. Changes in hourly electricity consumption under COVID mandates: A glance to future hourly residential power consumption pattern with remote work in Arizona. *Appl. Energy* **2022**, *310*, 19. [CrossRef]
79. Cribb, J.; Gotlibovych, I.; Sykes, D. Domestic Energy Usage Patterns during Social Distancing. 22 March 2020. Available online: https://octopus.energy/blog/domestic-energy-usage-patterns-during-social-distancing/ (accessed on 10 October 2022).

80. Huebner, G.M.; Watson, N.E.; Direk, K.; McKenna, E.; Webborn, E.; Hollick, F.; Elam, S.; Oreszczyn, T. Survey study on energy use in UK homes during COVID-19. *Build. Cities* **2021**, *2*, 952–969. [CrossRef]
81. Benatia, D. Ring the alarm! Electricity markets, renewables, and the pandemic. *Energy Econ.* **2022**, *106*, 23. [CrossRef]
82. Snow, S.; Bean, R.; Glencross, M.; Horrocks, N. Drivers behind Residential Electricity Demand Fluctuations due to COVID-19 Restrictions. *Energies* **2020**, *13*, 5738. [CrossRef]
83. Cheshmehzangi, A. COVID-19 and household energy implications: What are the main impacts on energy use? *Helyon* **2020**, *6*, 24. [CrossRef]
84. Bielecki, S.; Skoczkowski, T.; Sobczak, L.; Buchoski, J.; Maciąg, Ł.; Dukat, P. Impact of the Lockdown during the COVID-19 Pandemic on Electricity Use by Residential Users. *Energies* **2021**, *14*, 980. [CrossRef]
85. Carvalho, M.; de Mello Delgado, D.B.; de Lima, K.M.; de Camargo Cancela, M.; dos Siqueira, C.A.; de Souza, D.L. Effects of the COVID-19 pandemic on the Brazilian electricity consumption patterns. *Int. J. Energy Res.* **2020**, *45*, 3358–3364. [CrossRef]
86. Bollino, C.A.; d'Errico, M.C. Electricity Demand Elasticity, Mobility, and COVID-19 Contagion Nexus in the Italian Day-Ahead Electricity Market. *Energies* **2022**, *15*, 7501. [CrossRef]
87. Wakashiro, Y. *Causal Impact of Severe Events on Electricity Demand: The Case of COVID-19 in Japan*; Center for Social Systems Innovation, Kobe University: Kobe, Japan, 2022.
88. Hansell, F.; Vällfors, A. Demand Side Management: How Has Residential Electricity Demand Changed during the Corona Pandemic? Ph.D. Thesis, KTH School of Industrial Engineering and Management, Stockholm, Sweden, 2021. Available online: https://www.diva-portal.org/smash/get/diva2:1581205/FULLTEXT01.pdf (accessed on 24 October 2022).
89. Khan, I.; Sahabuddin, M. COVID-19 pandemic, lockdown, and consequences for a fossil fuel-dominated electricity system. *AIP Adv.* **2021**, *11*, 055307. [CrossRef]
90. Alavi, A.; Sadid, S.; Ahmed, M.; Abid, F. Effect analysis of the COVID-19 pandemic on the electricity consumption of Bangladesh. *Helyon* **2022**, *8*, 12. [CrossRef]
91. Bhattacharya, S.; Banerjee, R.; Liebman, A.; Dargaville, R. Analysing the impact of lockdown due to the COVID-19 pandemic on the. *Int. J. Electr. Power Energy Syst.* **2021**, *141*, 20. [CrossRef]
92. Abulibdeh, A.; Zaidan, E.; Jabbar, R. The impact of COVID-19 pandemic on electricity consumption and electricity demand forecasting accuracy: Empirical evidence from the state of Qatar. *Energy Strategy Rev.* **2022**, *44*, 19. [CrossRef]
93. Rana, A.; Kamali, M.; Riyadh, M.M.; Sultana, R.S.; Kamal, R.M.; Alam, S.M.; Hewage, K.; Sadiq, R. Energy efficiency in residential buildings amid COVID-19: A holistic comparative analysis between old and new normal occupancies. *Energy Build.* **2022**, *277*, 112551. [CrossRef]
94. Jula, D.; Jula, N.-M. *Econometria Seriilor de Timp (Time Series Econometrics)*; Mustang: Bucurest, Romania, 2012.
95. Metcalf, L.; Casey, W. (Eds.) Metrics, similarity, and sets. In *Cybersecurity and Applied Mathematics*; Elsevier Inc.: Amsterdam, The Netherlands, 2016; pp. 3–22. [CrossRef]
96. ScienceDirect. Minkowski Distance. Available online: https://www.sciencedirect.com/topics/computer-science/minkowski-distance (accessed on 21 March 2022).
97. Dobrescu, E. Sectoral Structure and Economic Growth. *Rom. J. Econ. Forecast.* **2011**, *14*, 5–36. Available online: https://ipe.ro/rjef/rjef3_11/rjef3_2011p5-36.pdf (accessed on 21 March 2022).
98. Jula, D.; Jula, N.-M. Economic Growth and Structural Changes in Regional Employment. *J. Econ. Forecast.* **2013**, *16*, 52–69. Available online: https://ipe.ro/rjef/rjef2_13/rjef2_2013p52-69.pdf (accessed on 25 October 2021).
99. President of Romania. Decree on the Establishment of the State of Emergency in the Territory of Romania. Official Gazette of Romania Part I, No. 212. , 16 March 2020; p. 15. Available online: https://rm.coe.int/16809e375d (accessed on 6 May 2022).
100. President of Romania. Decree on the Extension of the State of Emergency in the Territory of Romania. Official Journal of Romania Part I, No. 311. , 14 April 2020; p. 24. Available online: https://rm.coe.int/16809e375e (accessed on 6 May 2022).
101. Soava, G.; Mehedintu, A.; Sterpu, M.; Grecu, E. The Impact of the COVID-19 Pandemic on Electricity Consumption and Economic Growth in Romania. *Energies* **2021**, *14*, 2394. [CrossRef]
102. Jula, D.-M. Impact of the COVID-19 Pandemic on the Romanian Electricity Consumption. *Glob. Econ. Obs.* **2021**, *9*, 166–179. Available online: http://www.globeco.ro/wp-content/uploads/vol/split/vol_9_no_1/geo_2021_vol9_no1_art_019.pdf (accessed on 4 November 2022).

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The Role of Renewable Energy Sources in Electricity Production in Poland and the Background of Energy Policy of the European Union at the Beginning of the COVID-19 Crisis

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Abstract: Electricity production in Poland is stable and ranges from 160–170 TWH a year. The share of renewable energy sources (RES) is increasing. Poland increased its share from 6.9% in 2010 to 12.7% in 2019 and 16.1% in 2020. The share of hard and brown coal decreased in Poland from 87.8% in 2010 to 73.5% in 2019. Wind energy (9.2%) and natural gas (9.2%) are the most important sources of RES in electricity production. The purpose of this research is to discover the changes in renewable energy production, and the impact on electricity production in Poland. Our research showed the extent of development of RES in Poland and other countries of the European Union. The share of renewable energy sources in electricity production increased as the effect of energy policy of the European Union. We also evaluated the impact of the COVID-19 crisis on the renewable energy market and electricity production in Poland, and other countries of the European Union. Because of the shortage of data, we presented changes at the beginning of the COVID-19 crisis in 2019–2020. First, we described the sustainable development and energy policy of the European Union. Then, we described and used methods, including regression analysis, as the most important method. We also found that the power capacity in Poland increased, with the increases coming from solar radiation (11,984%), wind energy (437.8%) and biomass installations (324.7%) in 2010–2020. The biggest electricity producers in the EU are France and Germany. These countries also use nuclear energy, which helps to meet the increasing demand. To check the impact of power installed from renewable energy carriers we conducted a regression analysis. This method provided a correlation between electricity production from renewable energy sources and investments in renewable energy carriers. We wanted to discover the impact of RES installations, and their impact on electricity production in Poland. The statistical analysis was based on data from 2010–2020. Our research points out that the most important factors shaping electricity production were installations using energy from solar radiation and hydropower installations.

Keywords: renewable energy sources; electricity production; energy policy; the COVID-19 crisis

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1. Introduction

Renewable energy sources (RES) play a key role in delivering clean energy in the European Union (EU) and the world. Such energy sources prevent rises in temperature for the world's climate. Moreover, the EU will be the modern economy using RES. The problem of energy diversification and decreasing the contamination of the environment is particularly important. Renewable energy sources deliver clean energy, which can solve many problems with greenhouses gases emissions. Moreover, strict European Union energy policy forces member states to increase their energy independence from Russia. Renewable energy sources are also important in electricity production and electricity is a key factor in the economy, population, imports and exports [1]. Electricity production and demand also has an impact on gross domestic product (GDP) creation in the economy [2,3].

Energy is mainly used in electricity, heat, and motor fuel. Fossil fuels deliver about 82% of primary energy [4]. In Poland, 90% of electricity was produced from coal in 1960–2008. Environmental awareness and European Union policy forced Polish government to reduce the utilization of coal [5]. Today, coal and lignite create 80% of the electricity, whereas in Europe it is 25% [6]. Hard coal and lignite are the main source of electricity in the world. In Poland, for example, hard coal and lignite generated more than 56% of primary energy and more than 85% of electricity production [7].

Moreover, the use of coal creates the problem of mining wastes. The problem has national and international repercussions [8]. However, the share of fossil fuels in electricity production is decreasing, because they generate climate change and have a big carbon footprint. Fossil fuels affect people worldwide, especially in low-income communities. The negative impact is strengthened in populations with inadequate nutrition and poverty [9]. Most countries vowed to reduce coal consumption, for example, China by 15% by 2040, compared to 2016 [10,11]. Moreover, coal utilization creates environmental problems, including ash production as an effect of combustion, and sulfur and mercury removal [12].

The economic situation for the energy sector in Poland was influenced by the post-communist countries at the beginning of the 1990s. Poland was self-sufficient in coal production, but after accession to the European Union it had to adjust to a new energy policy [13]. In the long term, the strategy of the European Union directed on hard coal reduction may lead to negative effects [14]. The most important criteria for purchasing coal by consumers is its price [15]. This situation is particularly evident today, during war between Russia and Ukraine, which led to a tremendous increase in the price of coal. Poland had to import more than 6 million tons of coal to fill the demand in the market in 2022. The cost of environmental fees for CO_2 emission allowances impacted the level of the price increase for energy in Poland. The costs for green certificates are responsible for 60% of the price increase for energy for consumers. The EU trading system of green certificates should be discussed, and the reliable levels of emissions should be elaborated upon. Polish hard coal mining is becoming less competitive because of increasing prices of coal [16]. The future of Polish mining depends on coal preparation, coal quality and the exploitation system. Moreover, the decisive role will depend on environmental regulation and policy [17].

RESs include biomass, wind energy, photovoltaics, biofuels, biomass and heat pump [18]. Biomass and other renewable energy sources are the tool which help to resolve the problems of environmental contamination [19]. The production of electricity from wind and solar energy has increased worldwide. However, these kinds of energy can be unstable and dependent on weather conditions. Wind produces less energy on windless days and solar produces less energy when there is less snow in winter [20].

The most important advantages in energy production for non-renewable energy sources is that they produce electricity and heat at lower costs. However, renewable energy sources are more economically sustainable [21]. Fossil fuels should be abandoned because the world is going to decrease the temperature 2 °C above pre-industrial levels [22]. Carbon dioxide and methane are the main greenhouse gasses coming from fossil fuels, which are responsible for global heating [23].

The literature providing information about RES, fossil fuels and electricity production is readily accessible [20,21,24]. However, little attention is given to the impact of the COVID-19 crisis on the renewable energy and electricity production sector. Our paper contributes to the existing literature on RES and the impact of the COVID-19 crisis on this sector. When the COVID-19 virus spread across the entire world it had tremendous impact on human health, causing not only disease but also the deaths of many people. Therefore, policy frameworks should consider the impact of a health event not only in the health sector, but also in energy and other sectors [25]. Some concerns include the social and economic sphere and the increase of electricity prices. In 2019, the electricity price increased +9.7% and in 2020 reached +14.1%. In September 2021 the electricity price reached the level 401 PLN/MWH net compared to 239 PLN/MWH net in October 2020 [26].

The purpose of this research was to present the development of RES in relation to electricity production in Poland, in the context of the EU at the beginning of the COVID-19 crisis. An attempt was made to answer the following questions:

1. What is the share of renewable energy sources in energy production and consumption in Poland, and what is the impact of the COVID-19 crisis on the sector?

2. What development of renewable energy sources has been observed and what is the contribution to energy production in Poland at the beginning of the COVID-19 crisis?

3. What policies influence the development of renewable energy sources?

The following research hypotheses were formulated based on a review of the literature:

Hypothesis 1 (H1). *The share of renewable energy sources production in Poland has improved after accession to the European Union (EU), but at the beginning of COVID-19 it decreased as a result of lower demand for electricity*.

Hypothesis 2 (H2). *The European Union (EU) policies support the development of renewable energy sources in Poland, which has a positive impact on clean energy production*.

The paper includes the following parts: Section 1 is introduction, and Section 2 literature review. Later, we present Section 3 which is the methods. The main sections are the research results and discussion. The final section is the conclusion.

2. Conditioning and Energy Policy of the European Union and World

Renewable energy sources deliver clean energy preventing climate before temperature rise, and foster the development of the economy of EU. The climate changes limited to the increase of carbon dioxide (CO_2) force the European Union to elaborate policy. The new policy should be adopted to lower the original level of CO_2 [27].

The problem of energy can be solved by delivering eco-efficiency and sustainable development introduction. This can be achieved by elaborating processes reducing methane and greenhouse gas emissions, drainage water and by processing waste [28,29].

Smog, as the effect of fossil fuel utilization, can be reduced by natural and environmental policy, which aims to reduce the so-called stock emissions [30]. This is a very big problem in the transition of Polish and other European Union countries towards a carbon economy. Poland, whose energy system is based on fossil fuels, has a problem with the transformation of this sector [31].

In the mining industry, the supply side of policies include limiting carbon, solving down investments in fossil fuel and reducing the cost of production [32]. The biggest producers of coal, such as China, elaborated national standards to adopt the environmental requirements. The local coal-product standards have been elaborated and there is a strong pressure on clean manufacturing for coal production and consumption [33]. China as a leader of coal production is also big emitter of CO_2, which causes environmental problems to the country. Coal production, processing and utilization is a challenge for many coal mines [34]. Moreover, energy efficiency improvement required investigations in coal pre-drying, energy equipment, boilers and power plant [35].

Europe is another big producer of coal and the mining industry. The area is particularly vulnerable to environmental protection [36]. Many countries of the European Union face a shock decrease of hard coal prices, caused by their inefficiency. Such a dramatic situation in many coal plants was observed in 2012 and 2014 [37]. Moreover, the current dramatic situation on the energy sector in the European Union, caused by the war between Russia and Ukraine, will lead to many coal plants collapsing. That is why energy plants should take up proper strategies to develop in the market. Those proper strategies should be to adjust to business and environmental conditions, and the companies should change, along with the changing environment, and take up organization reaction. The changes should have a positive impact on financial results and improve competitiveness [24]. Poland has adopted an energy policy through to 2030. The Polish energy sector is undergoing major challenges, including increasing demand for electricity, insufficient installation for energy, and low supplies of gas from Russia. Polish policy includes the improvement of efficiency for energy, energy security, the diversification of electricity sources, and pollution reduction. According to that policy, the demand for energy from RES in 2030 should be: electricity (33,296 Ktoe), wind (1530 Ktoe), solid biomass (994 Ktoe) and biogas (592 Ktoe). These numbers should lead to an increase in the use of RES in final energy consumption to 15% in 2020, an increase in the share of biofuels to 10% in 2020, and the greater protection of forests and the environment [38].

The theory describing sustainable development and energy is wide in the European Union. Worth mentioning is the 'Agenda 2000′, which introduced the European Union's rural development policy focused on resource management and climate preservation [39]. The Common Agricultural Policy (CAP) is the main policy regulating the development of farms and rural areas in European Union countries. More and more attention withing this policy is paid to the clean environment, greening agriculture and renewables. This is due to the fact that agriculture is delivering goods for nutrition, but also for energy (biomass, biogas) and the landscape. In economic theory, goods include environmental aspects, production, food production and others [40].

The European Union energy policy is the Renewable Energy Directive (RED) of 2009, which had an aim of "20/20/20′′. This included 20% as the renewable energy target and 10% as the energy target for the transport sector [37]. Another important directive was approved in 2018 and was called the Renewable Energy Directive (RED II). The directive set a new target of 32% of renewable energy sources and 14% for transport by 2030 [41].

Additionally, the European Union prepared the Communication on the European Green Deal, aimed at carbon neutrality by 2050. This Green Deal will result in several changes from the previous document RED II [41].

In 2014, the European Council maintained the direction of counteracting climate change and approved four goals for the 2030 perspective for the entire EU, which, after revisions in 2018 and 2020, have the following shape:

- the reduction of greenhouse gas emissions by 55% compared to 1990 emissions;
- at least a 32% share of RES in gross final energy consumption;
- an increase in energy efficiency by 32.5%;
- to complete the internal EU energy market.

The Polish energy policy is based on the European Union policy, and it is in line with the core of the policy. Pillars of the Polish energy policy through to 2040 are [42]:

1. just transformation;
2. a zero-emission energy system;
3. good air quality.

Detailed objectives of Poland's energy policy through to 2040 are:

1. the optimal use of own energy resources;
2. the development of electricity generation and network infrastructure;
3. the diversification of supplies and the expansion of the network infrastructure of natural gas, crude oil and liquid fuels;
4. the development of energy markets;
5. the implementation of nuclear energy;
6. the development of renewable energy sources;
7. the development of heating and cogeneration resources;
8. improved energy efficiency.

However, the COVID-19 pandemic contributed to the climate and environmental crises negatively impacting human health, and these circumstances will undoubtedly change the policy of the EU. The development of RES will not only be a challenge but will also deliver environmental benefits, such as: a reduction of greenhouse gas, such as CO_2 and methane; improve the management of biomass stock; and introduce new technologies in photovoltaics, wind and other renewable energy installations [43].

3. Materials and Methods

3.1. Data Sources

The EUROSTAT was the main source of data for this study. These are data presented in Eurostat databases and are accessible worldwide. These data are free of charge [44].

Other sources of data were derived from Statistic Poland and current information for 1990–2019 [45]. According to the data, the most important electricity producers are China, the USA, India and Russia. The largest increases in global electric production were observed in China (1108%) and India (441.6%) in 1990–2019. The USA is also a big producer of electric and it takes second place after China. In Poland, production increased by 20.2% and in Russia 3.3%, in 1990–2019 (Table 1).

Table 1. Electric energy production in the world in 1990–2019.

Year	TWH	China (TWH)	%	USA (TWH)	%	India (TWH)	%	Russia (TWH)	%	Poland	%
1990	11,957.4	621.2	5.2	3232.8	27.0	287.8	2.4	1082.2	9.1	136.3	1.1
2000	15,555.2	1355.6	8.7	4052.3	26.1	571.4	3.7	877.8	5.6	145.2	0.9
2010	21,569.8	4207.2	19.5	4394.3	20.4	937.5	4.3	1038.0	4.8	157.7	0.7
2019	27,004.7	7503.4	27.8	4401.3	16.3	1558.7	5.8	1118.1	4.1	163.9	0.6

Source: Own elaborations based on [40].

3.2. Methods

To analyze changes in the development of RES in the EU and Poland we employed different analyses. First, regression analysis.

This model shows the impact of independent variables on the dependent variable (electricity production from renewable energy sources in Poland (GWh)). The basis of using the variables was the possibility to access the data. The data describes the most important investments in installations in renewable energy in Poland. These investments impact electricity production from RES in Poland.

The multivariable regression function can be written as follows [46]:

$$Y = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \ldots + \alpha_k X_k + \xi, \quad (1)$$

where

Y—dependent variable;

X_i—explanatory variables (i = 1, 2, ..., k);

ξ—random component;

α_0—intercept of regression function;

α_i—structural parameters of the model (i = 1, 2, ..., k).

We used the method of least squares to perform the regression analysis. We used the Statistica 13.3 program for data analysis. The method is widely used to analyze the results.

The selection of dependent variables resulted from their importance for energy production from renewable energy sources and the accessibility of the data. The selection of the independent variables was made based on the substantive justification of their impact on the production of renewable energy sources. In this respect, exogenous variables were considered. Then, from the set of presented variables, variables with high autocorrelation were eliminated [46]. We chose a few variables that had a statistically significant effect on the production of electricity from renewable energy sources.

To achieve the proper results, we chose the explanatory variables that were characterized by high volatility and were not correlated with each other. They were correlated with the explained variable: the production of electricity from renewable energy sources. The set of variables that influence electricity production from renewable energy sources are:

X_1—installations using biogas;

X_2—installations using biomass;

X_3—installations using the energy of solar radiation;

X_4—installations using wind energy;

X_5—installations using hydropower.

The explained variable was: Y_1—electricity production from renewable energy sources in Poland (GWh).

4. Results

4.1. Share of Renewable Energy Sources (RES) in the European Union (EU)

Renewable energy sources (RES) have been developed in the EU. The share of renewable energy in heating and cooling will increase by about 1.1% on average annually in the years 2020–2030. Additionally, the use of biomass will play a key role in increasing energy from RES [47].

The main source of RES in Poland is biomass, which is mostly obtained from forests. Typically, developing countries use biomass from forests but more developed countries, like those in western Europe, use a wider mix of renewable energy sources [48].

The COVID-19 crisis had an impact on RES in the EU. In 2020, compared to 2019, lockdowns resulted in declines in the use of gasoline (−13%), diesel (−9.4%), bioethanol (−10.1%) and biodiesel (−3.5%) [41]. The COVID-19 crisis led to the decrease in the value of the renewable energy market supply in 2020. In spite of the impacts of the pandemic, China the US, the UK, India and Spain represented 70% of new wind installations [48]. The COVID-19 crises was a challenge for the renewable energy sector, which resulted in the disruption of manufacturing facilities, companies, supply chains and transition to renewables [49].

To improve the situation, renewable energy technologies should be implemented, which helps to organize the usage of these sources [50]. As we can see from Figure 1, the largest share of renewables in the EU came from Sweden and Finland; that was the effect of energy sources from wood and other renewables. In Poland and other EU countries, there is a shift to RES because they have lower carbon emission and produce clean energy. Moreover, the global increase of energy demand with an average annual rate of 2.2 percent created the need to replace conventional resources based on hard coal and lignite. The replacement of fossil fuels requires an investment in a smart grid, which can be adjusted and installed in local conditions [51].

The existing stage of energy infrastructure is not in a good position. The electricity use in line requires amendments of the line and additional investments. This is particularly important in the decarbonization process to avoid climate contamination. The electricity infrastructure is extremely important [52]. For many years, the development of economies was based on the exploitation of natural resources, causing environment degradation. In addition to that, the increasing demand for hard coal and lignite caused the harmful waste to increase [53].

The COVID-19 crisis also affected electricity production and consumption worldwide. Declines in investments, staff layouts and reduced commercial activities have all been observed. The COVID-19 crisis undoubtedly caused a decrease in the energy sector due to less demand in production and consumption [54]. However, the lockdown did have a positive impact on the environment, through the reduction of emissions of greenhouse gasses [55].

As we can see, the share of electricity from renewable sources in the gross final consumption of energy in the electricity sector was the highest in 2020 (16.24%). At the beginning of the COVID-19 pandemic, the volatility in the global economy and lockdowns created a drop in renewable installations (Figure 2). The global fossil energy and renewable energy markets are undergoing big crises that will also impact Polish markets [56].

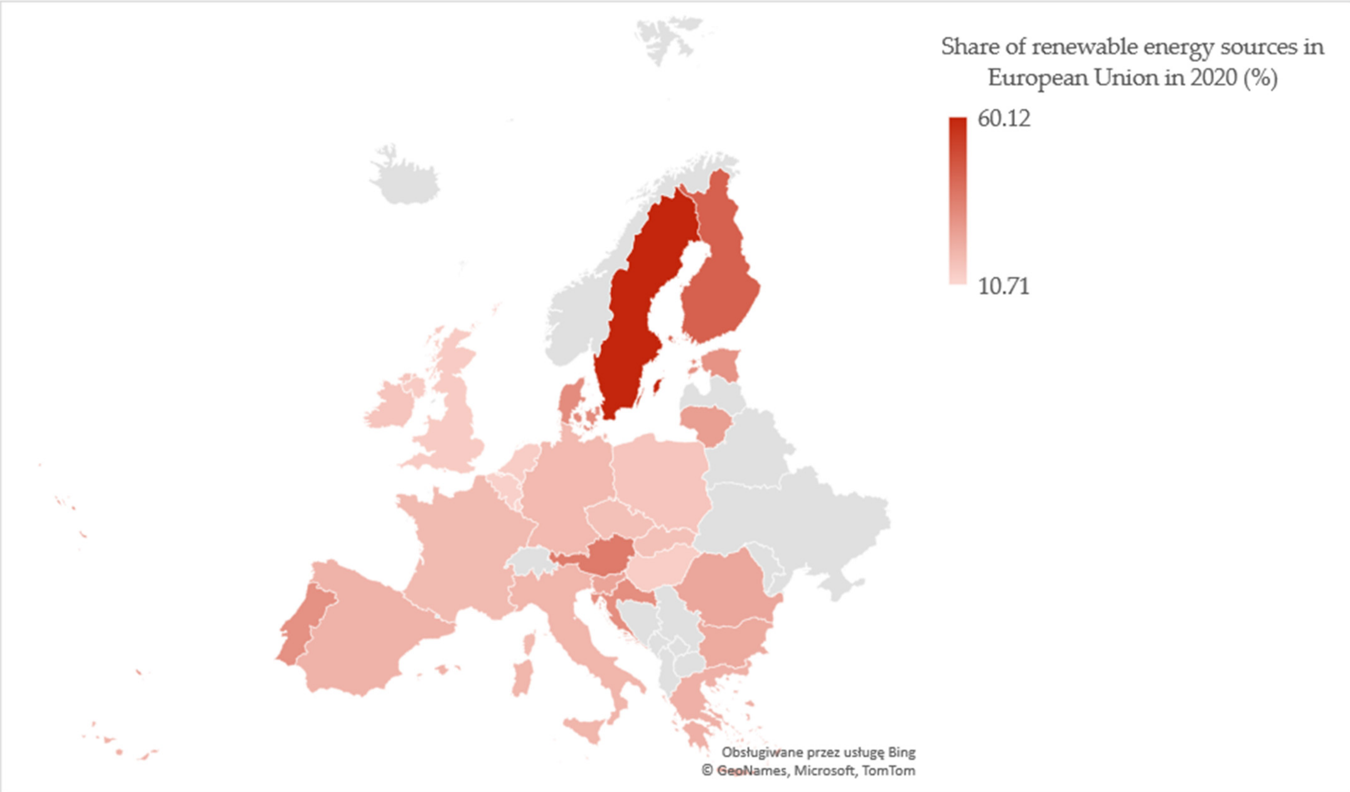

Figure 1. Share of renewable energy sources in European Union in 2020. Source: own elaborations based on [43].

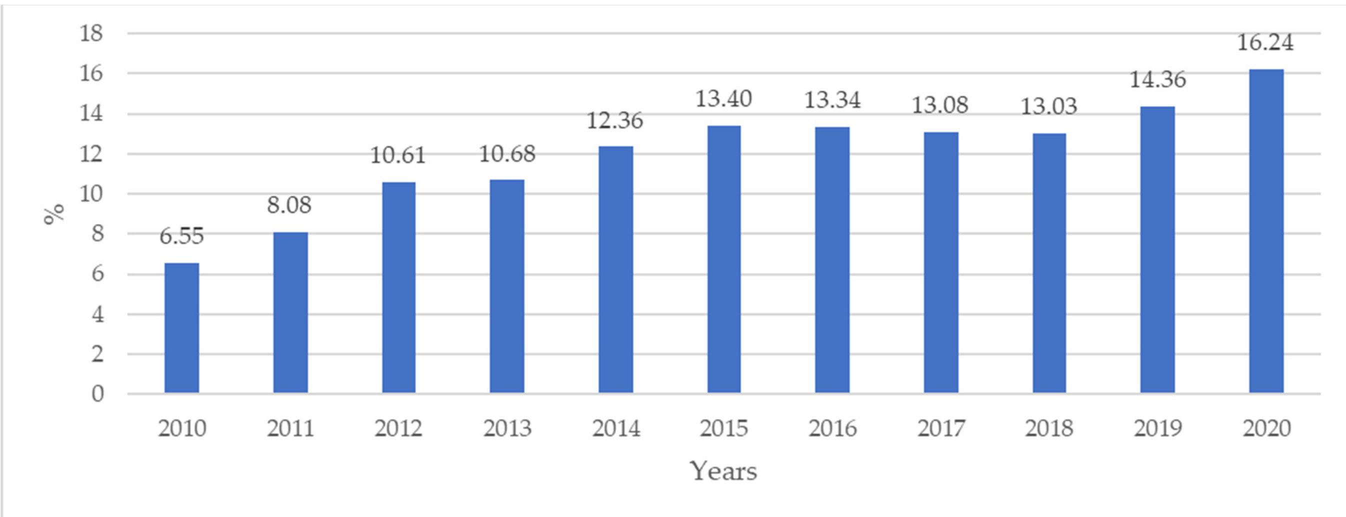

Figure 2. The share of electricity from renewable sources in the gross final consumption of energy in the electricity sector in Poland (%). **Source:** own elaborations based on [44].

The system of green certificates in Poland regulates the functioning of energy companies in order to obtain the proof of origin of electricity; otherwise, they must pay a compulsory fee [19]. The costs of daily CO_2 emissions increased from EUR 30/ton in January 2020 to EUR 85/ton in December 2021. In Poland, the highest electricity price increase was observed. The COVID-19 pandemic caused the global electricity price increase, material cost increases and disruptions in supply chains [57].

The Polish electricity system is dominated by electricity from hard and brown coal. However, the share of hard and brown coal in electricity production decreased from 87.8% in 2010 to 73.5% in 2019 (Figure 3). The changes observed in the structure of electricity production in Poland are the effect of global problems. Pollution from the use of fossil fuels is increasing global warming and continuing the exploitation of natural resources. As a result, the effects on migrations, not only of animals but also people, can be observed [58].

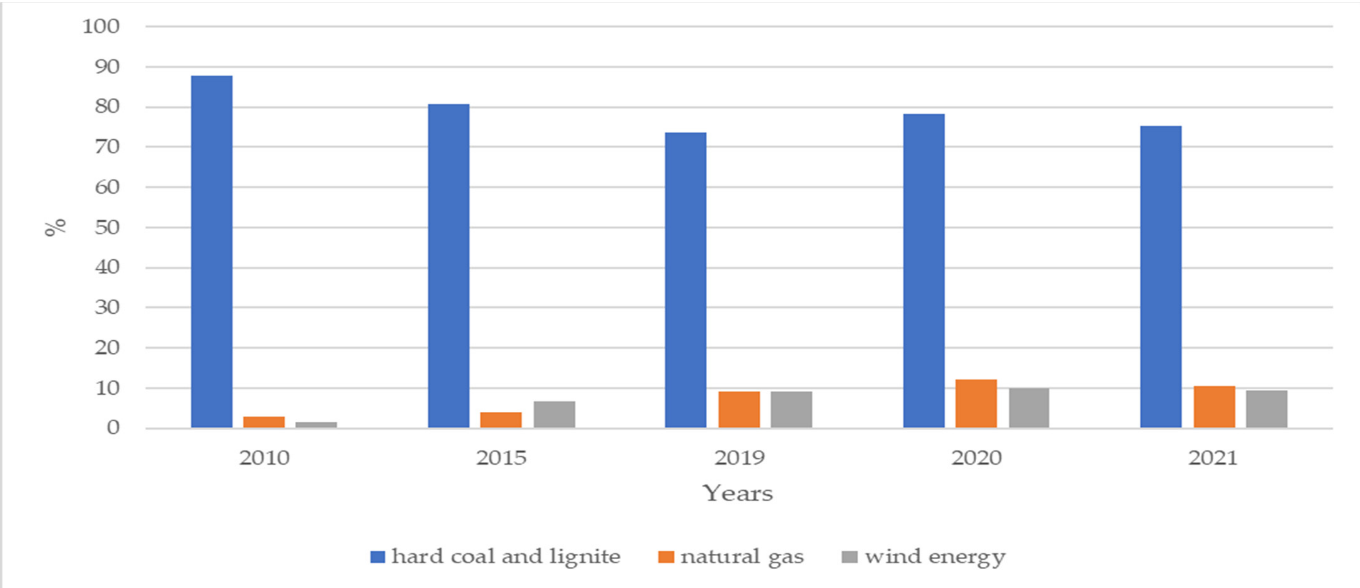

Figure 3. The structure of electricity production in Poland in 2010–2021 (%). **Source:** own elaborations based on [44].

Wind energy and natural gas increased their share of electricity production in Poland from 2010–2019. However, Poland belongs to the European Union and this region has had problems with the energy markets. The problems occurred not only in the EU but also in Asia, where such countries like India had low market volatility and low carbon sources for energy generation [59].

The COVID-19 pandemic impacted the energy sector, too. The mobility of people decreased during lockdowns and economies shrunk. The changes resulted in a 50% reduction in the demand for transportation, resulting in global crude oil price reductions. Moreover, the inter-continental trade from China to Europe and other countries decreased, causing a decrease in technologies being imported [60].

Poland is increasing installation capacity from renewable energy sources. The biggest capacity was installed in 2020 from wind energy (6347.1 MW) and biomass installation (1512.9 MW), and the smallest in biogas (255.7 MW) and hydro energy installation (976 MW). The installed capacity increased in all sectors. The largest increase was from solar energy installations. This was due to the development of photovoltaic (PV) and changed regulations for consumers. Large increases in RES came from installations of wind energy, a 438% increase in 2020 compared to 2010, and for biogas production with an increase of 208% (Table 2).

Table 2. Power of installed capacity in Poland (MW).

Year	Power Installed in Poland [MW], as at 31 December 2020				
	Installations Using Biogas	**Installations Using Biomass**	**Installations Using the Energy of Solar Radiation**	**Installations Using Wind Energy**	**Installations Using Hydropower**
2010	82.884	356.190	0.033	1180.27	937.044
2011	103.487	409.680	1.125	1616.361	951.390
2012	131.247	820.700	1.290	2496.74	966.103
2013	162.241	986.873	1.901	3389.541	966.103
2014	188.549	1008.245	21,004	3833.832	977.007
2015	212.497	1122.670	108.00	4582.036	981.799
2016	233.967	1281.065	187.25	5807.416	993.995
2017	235.373	1362.030	287.09	5848.671	988.377
2018	237.618	1362.870	561.98	5864.443	981.504
2019	245.366	1492.875	1539.26	5917.243	973.095
2020	255.699	1512.885	3954.96	6347.111	976.047
Changes 2010 = 100%	208.5	324.7	11,984	437.8	4.2

Source: own elaborations based on [44].

The solar system helps the photovoltaic system (PV) to produce energy. The photovoltaic (PV) and wind installations are becoming more popular not only in Poland but also in the EU and around the world. These kinds of energy help to decrease the use of fossil fuels and carbon dioxide emissions (CO_2). Moreover, these kinds of energy installations are based on small microgrid systems, which can be easily adjusted to local conditions [61]. The microgrid systems also have difficulties in implementation because of power quality, voltage, sustainability and other factors [62]. However, microgrids have more advantages because they can reduce greenhouse gas emissions and deliver cheap, clean, and reliable power [63]. The investment in microgrid installation can reduce the costs of electricity and increase comforts for customers [64].

Even though the development of RES has increased, this sector has still had a number of challenges. The operation of solar projects had supply disruptions. Different categories of solar had problems worldwide; however, the biggest issues were observed in rooftop solar systems [65].

However, the COVID-19 pandemic had an influence on the whole energy and renewable energy sector. Jobs were put at risk and the unemployment rate increased. The energy companies met the barrier of demand for electricity [66]. The increase of RES in Poland and other countries of the European Union are due to climate and energy policy goals of the EU, which are directed at greenhouse gas reduction by 55% in 2030, compared to 1990 [46].

As we can see from Table 2, the power capacity in Poland is increasing. This situation suggests that we cannot rely on coal and lignite because they are detrimental to the environment. Moreover, the high health aspects of raw materials are obstacles to their development [67].

4.2. Electricity Production in Poland and the EU

Electricity production is a key issue in the development of energy sectors worldwide. The development of the energy sector depends on policy, consumer needs and modern technologies. Moreover, the development of energy systems depends on its efficiency, investments and renewable energy sources [68].

The demand for electricity is increasing. It is an important input for the development of the economy. It is used in almost all kinds of human life, for example in industry, services, agriculture, heating and transport [69]. Another important issue is electricity consumption prediction. It helps to adjust facilities and energy industry to increase demand. Energy supply is important for not only consumers households, but also for communes and whole countries and regions [70].

The production of electricity in Poland is stable and it ranged from 157.7 TWH in 2010 to 163.5 TWH in 2019. However, the biggest electricity production was in 2017—170.5 TWH and 2019—170 TWH (Figure 4).

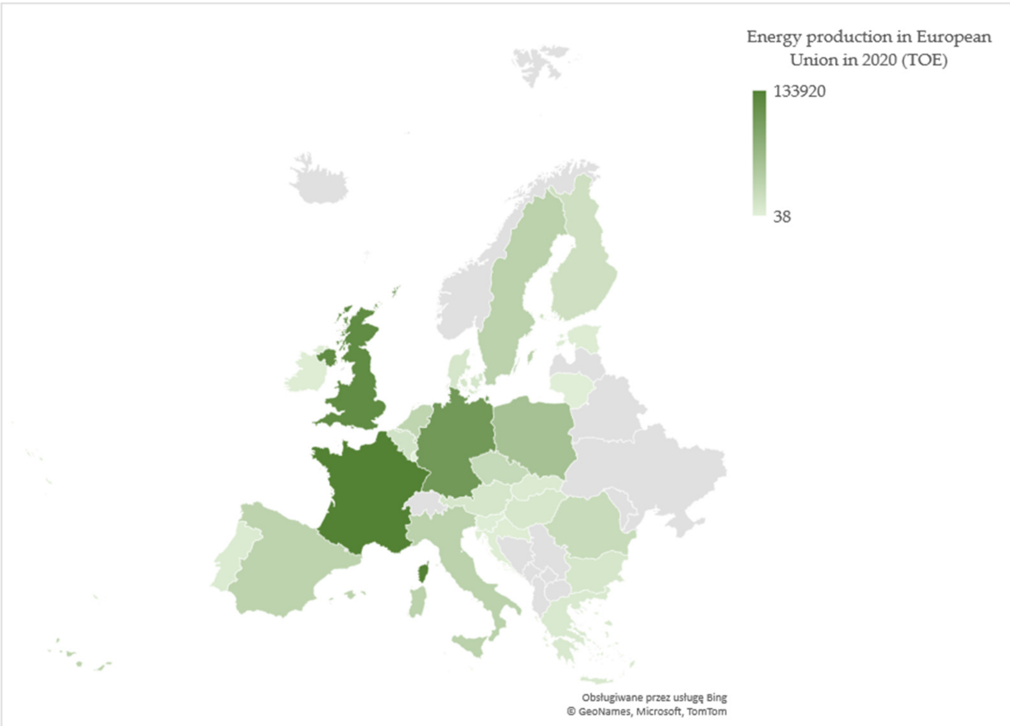

Figure 4. Energy production in European Union countries in 2020 (TOE). Source: own elaborations based on [43].

At the beginning of COVID-19 electricity production decreased as the effect of lower energy demand. This led to big problems with power installation and energy markets, which suffered from continuous changes. As we can see from Figure 5, the production of renewable energy decreased in 2019–2020. Then, in 2021 the production increased as recovery of the energy markets from the COVID-19 crisis; consumption, for example, is similar to production and in 2021 it was 174.4 TWH, which is a little bigger than production. The deficit was overcome by importing energy from Ukraine.

Analysis of the structure of electricity sources presented in Figure 6 prove that the most important source of energy in Poland is hard coal (44.3%) and lignite (24.4%). The following positions are taken by renewable energy sources, such as wind power installations (13.6%), natural gas (7.6%) and photovoltaic power plants (5.2%). These results are quite promising, and they point out that Poland has the chance to be a leader in RES and transform its energy economy into one using modern renewables.

The smallest share in renewable energy sources was gained by gas from coal seams, hydroelectric power plants and pumped storage power plants. This is because Poland does not have its own technology and has to import it from other EU countries and across the world. Moreover, Polish consumers are not fully convinced about the new technologies and their installation requires higher inputs on investments (Figure 6).

The effect of selected variables on the production of electricity from RES are presented in Table 3. The production of electricity from RES was the explained variable. The explanatory variables are in the Materials and Methods section.

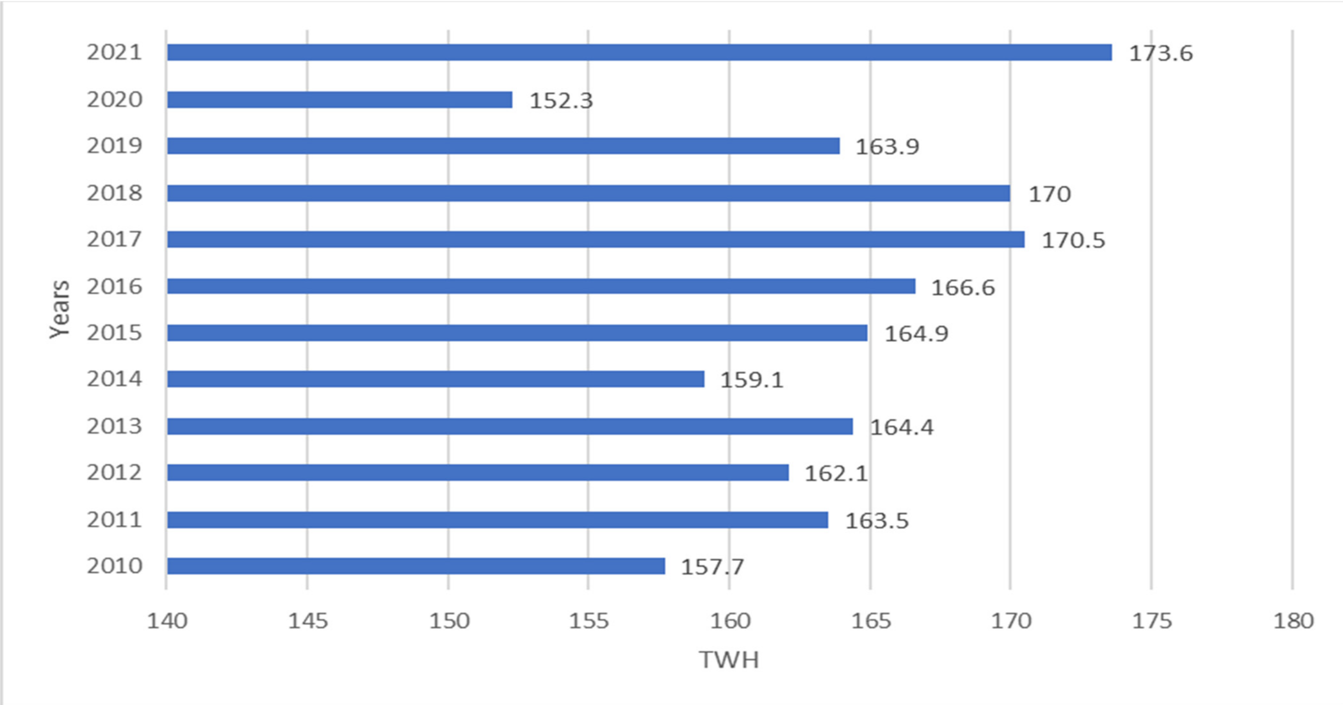

Figure 5. Electricity production in Poland in 2010–2021 (%)**. Source:** own elaborations based on [44].

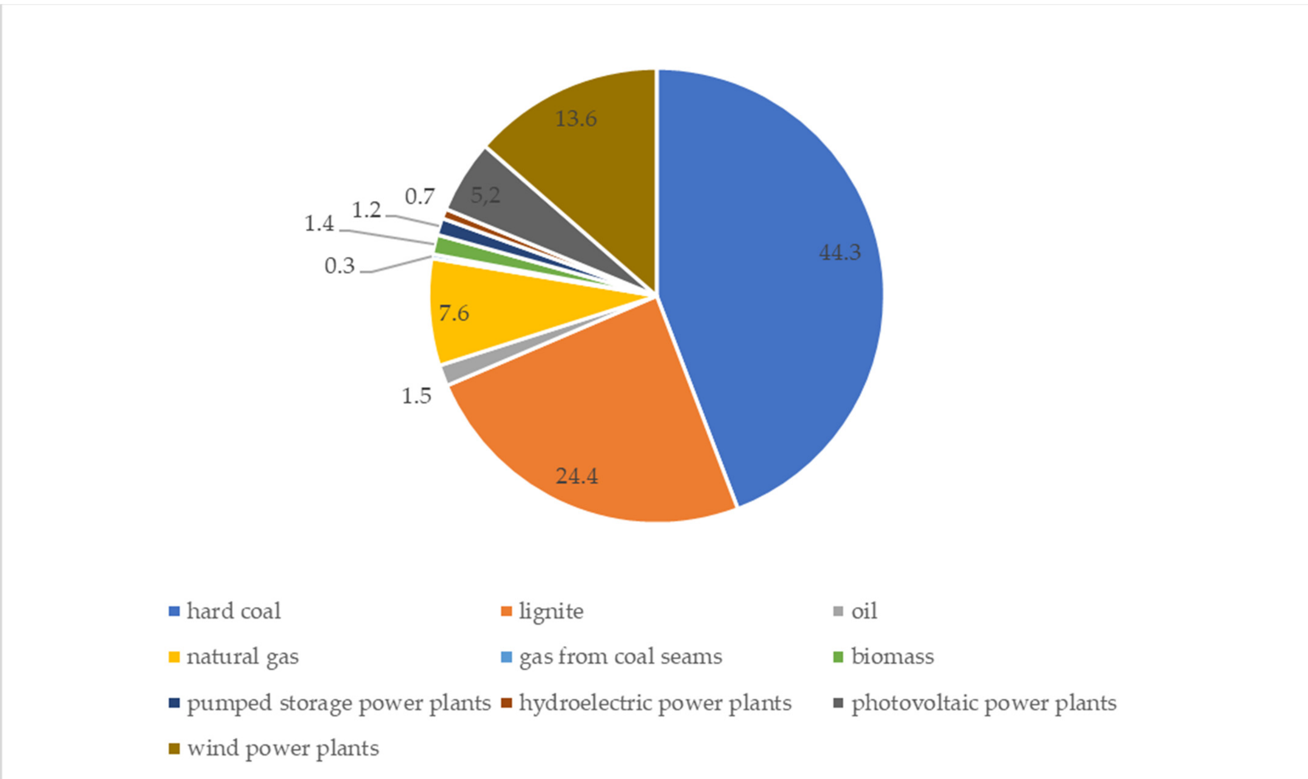

Figure 6. Structure of electricity production sources in Poland in 2022 year (%). **Source:** own elaboration based on [71].

Table 3. Results of the multiple regression analysis investigating the relationship between the dependent variable Y_1 (electricity production from renewable energy sources) and the explanatory variables.

	Coefficient	Std Error	Student's *t*-Test	*p*-Value
Intersept	−3.229	1.253	−2.628	0.046
X_1—Installations using biogas	−6568.65	12765.2	−0.514	0.628
X_2—Installations using biomass	−880.39	1018.7	−0.864	0.427
X_3—Installations using the energy of solar radiation	905.72	109.9	8.242	0.000
X_4—Installations using wind energy	−36.11	371.12	−0.097	0.926
X_5—Installations using hydropower	35,998.6	13643.2	2.639	0.046
Arithmetic means of the dependent variable	257,487.3	Standard deviation of dependent change		790,048.4
Sum of squares of residuals	2.77	Standard error of residuals		235,513.2
R-squared determination coefficient	0.955	Corrected R-square		0.9111
F(9, 197)	21.506	The *p*-value for the F-test		0.002
Likelihood logarithm	−147.35	Critical Information Akaike criterion		306.673
Critical Bayesian Schwarz criterion	309.060	Critical Hannan–Quinn criterion		305.168

Source: own elaboration based on [44].

As we can see from Table 3, the most important variable was X_3—installations using the energy of solar radiation and X_5—installations using hydropower. The results demonstrate that electricity production from renewable energy sources depended mostly on these factors. The developed model fitted the data well, as evidenced by a high R^2 (R^2 = 0.91; F = 21.506). Table 3 indicates that 91% of the variations of energy production are caused by independent variables. The F-statistics demonstrate a highly significant level for the model. Based on the equation, investment in solar energy will cause 1,47 TWH in Poland. Moreover, investments in installations using biogas will cause 1.15 TWH in Poland.

The regression equation is as follows:

$$Y_1 = -3.229 + -6568.65X_1 - 880.39X_2 + 905.72X_3 - 36.11X_4 + 35998.6X_5$$

The model explains the development of electricity production from renewable energy sources in Poland. Biomass, which has the biggest deliver of electricity, did not have such impact. The trend with the use of biomass will change, its share will decrease, whereas the share of energy from wind and photovoltaic will increase. Hydropower installations, which are also important, will not play a decisive role in Poland as its share in energy production is small.

The choice of model was carried out based on data analysis. We did three tests to analyze the model: the Durbin-Watson test, the White test and the Breush-Pagan test. The test results are presented in Table 4. Based on the research results from Table 4, we cannot reject the null hypotheses of these tests. The null hypothesis in the Breusch-Pagan test is about the lack of differentiation of individual effects and cannot be rejected. The *p* values for three tests are quite high.

Table 4. Results of the tests for the model.

Tests	Explained Variable-Electricity Production from Renewable Energy Sources	*p* Value
Durbin-Watson test	2.56645	0.213
White test	11.000	0.357
Breusch-Pagan test	3.343	0.647

Source: own elaboration based on [44].

5. Discussion

Renewable energy sources are future energies, which has an influence on the EU economy. In the 21st century, the world faced many challenges including important events like the COVID-19 crisis, and the war between Russia and Ukraine. Research showed that the COVID-19 crisis caused a decrease in the use of fossil energy and renewable energy in the European Union [41].

The effect of the COVID-19 crisis resulted in decreased levels of air pollution. However, the lockdown had a negative impact on the economy and health levels of society. The use of fuels and other sources of energy decreased, causing a drop in climate contamination. Conversely, the relaxation in lockdown increased pollution emissions to the environment [54].

The Polish and European Union system is based on emission trade. Energy companies should have green certificates, which confirm property rights and support the production of energy from renewable energy sources [19].

The Polish energy system is undergoing changes from a command-and-control economy to a free market economy. However, the economy transformation caused both unemployment and energy consumption to increase. The fossil fuel market is declining because of requirements of the European Union, with the focus on creating a carbon-free economy by 2050. The COVID-19 crisis and the war between Russia and Ukraine deepened the problem of energy shortage. Renewable energy sources are an opportunity for the Polish energy sector because the coal sector is inefficient to meet demand. The cost of importing coal from Russia was lower than Polish production.

The development of RES and its share in energy production depends on policy makers. They should take into account all aspects of the development and the state of infrastructure, including lines and buildings. Local government should consider social consultancies, which help to define the problem and generate better solutions. Sustainability should be a priority and investment in renewable energy sources should be linked with innovations transfer.

Another important issue with the development of RES and their impact on electricity production is the importation and transfer of technologies. The innovative technologies must be adjusted to local conditions, which can be a problem. Moreover, the reduction of financial support for the mining industry may cause a lower use of hard coal and lignite, enhancing the need for electricity from more renewable energy sources.

Our research showed the key role of investments in developing renewable energy sources. Wind and photovoltaic will play a major role in energy production in Poland. The share of RES from biomass will decrease. Hydropower installation will fill the gap in the energy mix in Poland.

6. Conclusions

The Polish coal industry is undergoing crisis because of the policy of the European Union forcing the common market to introduce a carbon free environment. The sector needs the necessary investment, but the European Union is going to be a carbon free market by 2050. The problem will be solved by replacing carbon mines by renewable energy sources and nuclear energy [72–74]. A very important role will be played by agriculture, which delivers both biomass and biogas, but also leads to environmental degradation [75].

The results of the present study indicate that significant changes in the development of RES in the EU have occurred. Moreover, the COVID-19 crisis led to a reduction in demand for renewable energy sources with the drop in economic growth [48].

At the beginning of the COVID-19 crisis, the EU and the world observed a positive environmental impact globally because of the lower emissions of greenhouse gasses. The lockdown during COVID-19 positively impacted the environment [55]. However, the COVID-19 pandemic had negative impacts on both the health sector and the economy. Future policies should be characterized by financial support to reduce the negative effects of pandemics and to harmonize human existence with nature. The policy should include an holistic approach with different strategies, such as reducing the use of cars and promoting e-mobility and a low-carbon environment [60].

Our research showed the need for the continued development of renewable energy sources in Poland and other countries of the European Union. However, Poland still depends on fossil fuels, such as hard coal and lignite. The expanded analysis shows that the biggest share of energy production is still from hard coal (44.3%) and lignite (24.4%). Additionally, renewable energy sources are playing a more important role because the share of wind power is 13.6% and photovoltaic 5.2%.

The results of the regression analysis show that the coefficients of X_3—installations using the energy of solar radiation and X_5—installations using hydropower, were positive, showing that they are driving forces in the production of electricity from renewable energy sources. Based on these results we can recommend that the drivers of electricity production from RES should increase economic growth.

The installations in RES are developing well but the pace is not sufficient to cover the deficit in electricity production. RESs can fill in production deficiencies but the pace of their development should be faster. The investment in installations using the energy of solar radiation and installations using wind energy should be increased.

Our research also has implications for policy makers. For example, the photovoltaic installation obstacles should be eliminated. Next, a cost reduction should be implemented. The installation of a 10 MW system for household use is about PLN 40,000. This is too large a cost for the average family, which struggles with economic crisis. The next challenge to be solved with policy changes is energy storage from photovoltaics. The energy system is not prepared for storage, and energy is currently gathered by a national company. A policy promoting the local storage of energy from PV and other RES should be established.

This work analyses the impact of installations of RES on the production of electricity from these sources. Our research proved that the investment in renewable energy power installations helped to increase electricity production. Hypothesis 1, assuming that the share of renewable energy sources production in Poland have improved after accession to the EU, has been positively verified. Poland and other countries of the EU were obliged to increase the share of electricity production from RES. Until 2020, Poland had to reach 15% of renewable energy use in total energy. Poland fulfilled its obligations and reached the level of 16%.

Hypothesis 2, assuming that the EU policies support the development of renewable energy sources in Poland, which has a positive impact on clean energy production, has been verified. The EU and the national government of Poland is providing support for renewable sources installation, which creates demand for these energy sources.

This research also has limitations. The most important is the problem with access to the newest statistical data. The problem with access decreases the efficiency of this research and limits the possibility of other discoveries. Other limitations can be the problems with COVID-19 pandemic assessments. All the literature proves its negative impact on societal health and the economy, but no current research directly examines the impact on the energy sector.

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Nomenclature

°C	Degrees Celsius
CAP	Common Agricultural Policy
CO_2	Carbon dioxide
EU	European Union
GDP	Gross Domestic Product
PEP	Polish energy policy
PV	Photovoltaic
PLN	Polish currency zloty
RED	Renewable energy directive
RES	Renewable Energy Sources
UK	United Kingdom
USA	United States of America

References

1. Ünler, A. Improvement of energy demand forecast using swarm intelligence: The case of Turkey with projections to 2025. *Energy Policy* **2008**, *36*, 1937–1944. [CrossRef]
2. Kiran, M.S.; Özceylan, E.; Günfüz, M.; Paksoy, T. Swarm intelligence approaches to estimate electricity energy demand in Turkey. *Knowl. Based Syst.* **2012**, *36*, 93–103. [CrossRef]
3. Toksan, M.D. Ant colony optimization approach to estimate energy demand of Turkey. *Energy Policy* **2007**, *35*, 3984–3990.
4. Gustavsson, L.; Haus, S.; Lundblad, M.; Lundström, A.; Ortiz, C.A.; Sathre, R.; Le Truong, N.; Wikberg, P.-E. Climate change effects of forestry and substitution of carbon-intensive materials and fossil fuels. *Renew. Sustain. Energy Rev.* **2017**, *67*, 612–624. [CrossRef]
5. Li, Y.; Zhang, H.; Kang, Y. Will Poland fulfill its coal commitment by 2030? An answer based on a novel time series prediction method. *Energy Rep.* **2020**, *6*, 1760–1767. [CrossRef]
6. Kuchler, M.; Bridge, G. Down the black hole: Sustaining national socio-technical imaginaries of coal in Poland. *Energy Res. Soc. Sci.* **2018**, *41*, 136–147. [CrossRef]
7. Widera, M.; Kasztelewicz, Z.; Prak, M. Lignite mining and electricity generation in Poland: The current state and future prospects. *Energy Policy* **2016**, *92*, 151–157. [CrossRef]
8. Pactwa, K.; Woźniak, J.; Dudek, M. Coal mining waste in Poland in reference to circular economy principles. *Fuel* **2020**, *270*, 117493. [CrossRef]
9. Perera, F.P. Multiple threats to child health from fossil fuel combustion: Impacts of air pollution and climate change. *Environ. Health Perspect.* **2017**, *125*, 141–148. [CrossRef]
10. Li, Y.; Chiu, Y.-H.; Lin, T.-Y. Coal production efficiency and land destruction in China's mining industry. *Resour. Policy* **2019**, *63*, 101449. [CrossRef]
11. *International Energy Agency World Energy Statistics*; International Energy Agency: Prais, France, 2017.
12. Rahman, M.; Pudasainee, D.; Gupta, R. Review on chemical upgrading of coal: Production processes, potential applications, and recent developments. *Fuel Process. Technol.* **2017**, *158*, 35–56. [CrossRef]
13. Nyga-Łukaszewska, H.; Aruga, K.; Stala-Szlugaj, K. Energy Security of Poland and Coal Supply: Price Analysis. *Sustainability* **2020**, *12*, 2541. [CrossRef]
14. Gawlik, L.; Kaliski, M.; Kamiński, J.; Sikora, A.P.; Szurej, A. Hard coal in the fuel-mix of Poland: The long-term perspective. *Arch. Min. Sci.* **2016**, *61*, 335–350. [CrossRef]
15. Stala-Szlugaj, K. The development of the market of qualified coal fuels in Poland. *Miner. Resour. Manag.* **2017**, *33*, 95–108. [CrossRef]
16. Dubiński, J.; Prusek, S.; Turek, M.; Wachowicz, J. Hard coal production competitiveness in Poland. Mining Ecology and Exploitation of the earth's bowels. *J. Min. Sci.* **2020**, *56*, 322–330. [CrossRef]
17. Blaschke, W.S.; Baic, I. Coal mining and coal preparation in Poland. *Czas. Tech.* **2016**, *167–168*, 40–45.
18. Singh, A.S.N.; Mahapatra, A. Repeated wavelet transform based ARiMA model for very short-term wind speed forecasting. *Renew. Energy* **2019**, *136*, 758–768. [CrossRef]
19. Dzikić, M.; Piwowar, A. Ecological and economic aspects of electric energy production using the biomass co-firing method: The case of Poland. *Renew. Sustain. Energy Rev.* **2016**, *55*, 856–862. [CrossRef]

20. Balouch, S.; Abrar, M.; Abdul Muqeet, H.; Shahzad, M.; Jamil, H.; Hamdi, M.; Malik Abdul, S.; Hamam, H. Optimal Scheduling of Demand Side Load Management of Smart Grid Considering Energy Efficiency. *Front. Energy Res.* **2022**, *10*, 861571. [CrossRef]
21. Digan, E.; Seker, F. The influence of real output, renewable and non-renewable energy, trade, and financial development on carbon emissions in the top renewable energy countries. *Renew. Sustain. Energy Rev.* **2016**, *60*, 1074–1085. [CrossRef]
22. Johnsson, F.; Kjärstad, J.; Rootzén, J. The threat to climate change mitigation posed by the abundance of fossil fuels. *Clim. Policy* **2019**, *19*, 258–274. [CrossRef]
23. Perrera, F.; Nadeau, K. Climate change, Fossil Fuel Pollution, and Children's Health. *N. Engl. J. Med.* **2022**, *386*, 2303–2314. [CrossRef] [PubMed]
24. 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]
25. Srivastava, S.; Khokhar, F.; Madhav, A.; Pembroke, B.; Shetty, V.; Mutreja, A. COVID-19 Lessons for Climate Change and Sustainable Health. *Energies* **2021**, *14*, 5938. [CrossRef]
26. Chomać-Pierzecka, E.; Kokiel, A.; Rogozińska-Mitrut, J.; Sobczak, A.; Soboń, D.; Stasiak, J. Analysis and Evaluation of the Photovoltaic Market in Poland and the Baltic States. *Energies* **2022**, *15*, 669. [CrossRef]
27. Gil-Alana, L.; Gupta, R.; Perez de Gracia, F. Modeling persistence of carbon emission allowance process. *Renew. Sustain. Energy Rev.* **2016**, *55*, 221–226. [CrossRef]
28. Dubiński, J.; Prusek, S.; Turek, M. Key tasks of science in improving effectiveness of hard coal production in Poland. *Arch. Min. Sci.* **2017**, *62*, 597–620. [CrossRef]
29. Burchart-Karol, D.F.; Fugiel, A.; Czaplicka-Kolarz, A.; Turek, M. Model of environmental life cycle assessment for coal mining operations. *Sci. Total Environ.* **2016**, *562*, 61–72. [CrossRef]
30. Woźniak, J.; Krysa, Z.; Dudek, M. Concept of government subsidized energy prices for a group of individual consumers in Poland as a means to reduce smog. *Energy Policy* **2020**, *144*, 111620. [CrossRef]
31. Kiulia, O. Decarbonization perspectives for the Polish economy. *Energy Policy* **2018**, *118*, 69–76. [CrossRef]
32. Brauers, H.; Oei, P.-Y. The political economy of coal in Poland: Drivers and barriers for a shift away from fossil fuels. *Energy Policy* **2020**, *144*, 111621. [CrossRef]
33. Bai, X.; Ding, H.; Lian, J.; Ma, D.; Yang, X.; Sun, N.; Xue, W.; Chang, Y. Coal production in China: Past, present, and future projections. *Int. Geol. Rev.* **2018**, *60*, 535–547. [CrossRef]
34. Wang, N.; Wen, Z.; Liu, M.; Guo, J. Constructing an energy efficiency benchmarking system for coal production. *Appl. Energy* **2016**, *169*, 301–308. [CrossRef]
35. Xu, C.; Xu, G.; Zhao, S.; Dong, W.; Zhou, L.; Yang, Y. A theoretical investigation of energy efficiency improvement by coal pre-drying in coal fired power plants. *Energy Convers. Manag.* **2016**, *122*, 580–588. [CrossRef]
36. Badera, J.; Kocoń, P. Local community opinions regarding the socio-environmental aspects of lignite surface mining: Experience from central Poland. *Energy Policy* **2014**, *66*, 507–516. [CrossRef]
37. Vaněk, M.; Bora, P.; Maruszewska, E.W.; Kašparková, A. Benchmarking of mining companies extracting hard coal in the Upper Silesian Coal Basin. *Resour. Policy* **2017**, *53*, 378–383. [CrossRef]
38. Paska, J.; Surma, T. Electricity generation from renewable energy sources in Poland. *Renew. Energy* **2014**, *7*, 286–294. [CrossRef]
39. Czyżewski, B.; Guth, M. Impact of policy and factor intensity on sustainable value of European agriculture: Exploiting trade-offs of environmental, economic, and social efficiency at the regional level. *Agriculture* **2021**, *11*, 78. [CrossRef]
40. Czyżewski, B.; Majchrzak, A. Market versus agriculture in Poland–macroeconomic relations of income, prices, and productivity in terms of the sustainable development paradigm. *Technol. Econ. Dev. Econ.* **2018**, *24*, 318–334. [CrossRef]
41. Flach, B.; Lieberz, S.; Bolla, S. Biofuels Annual. Available online: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_The%20Hague_European%20Union_E42022-0048.pdf (accessed on 17 November 2022).
42. PEP 2040. Polityka energetyczna Polski do 2040 R (Energy Policy of Poland to 2040). Ministerstwo Klimatu i Środowiska. GUS Załącznik do uchwały nr 22/2021 Rady Ministrwó z dnia 2 lutego 2021. Available online: https://www.gov.pl/web/klimat/zalozenia-do-aktualizacji-polityki-energetycznej-polski-do-2040-r (accessed on 10 November 2022). (In Polish)
43. Tsao, Y.-C.; Thanh, V.-V.; Lu, J.-C.; Wei, H.-H. A risk-sharing-based resilient renewable energy supply network model under the COVID-19 pandemic. *Sustain. Prod. Consum.* **2021**, *25*, 484–498. [CrossRef]
44. Eurostat. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics#Share_of_renewable_energy_more_than_doubled_between_2004_and_2020 (accessed on 10 November 2022).
45. Statistics Poland. GUS 2020. Available online: https://www.ure.gov.pl/ (accessed on 10 November 2022).
46. Bórawski, P.; Bórawski, M.B.; Parzonko, A.; Wicki, L.; Rokicki, T.; Perkowska, A.; Dunn, J.W. Development of Organic Milk Production in Poland on the Background of the EU. *Agriculture* **2021**, *11*, 323. [CrossRef]
47. Koutroumanidis, T.; Ioannou, K.; Arabatzis, G. Predicting fuelwood prices in Greece with the use of ARIMA models, artificial neural networks, and a hybrid ARIMA-ANN model. *Energy Policy* **2009**, *37*, 3627–3634. [CrossRef]
48. Bhuiyan, M.A.; An, J.; Mikhaylov, A.; Moiseev, N.; Danish, M.S.S. Renewable energy development and COVID-19 measures for sustainable development. *Sustainability* **2021**, *13*, 4418. [CrossRef]
49. Hosseinin, S.E. An outlook on the global development of renewable and sustainable energy at the time of COVID-19. *Energy Res. Soc. Sci.* **2020**, *68*, 101633. [CrossRef] [PubMed]

50. Shah, M.I.; Kirikkaleli, D.; Adedoyin, F.F. Regime switching effect of COVID-19 pandemic on renewable electricity generation in Denmark. *Renew. Energy* **2021**, *175*, 797–806. [CrossRef]
51. Nasir, T.; Raza, S.; Abrar, M.; Muqeet, H.A.; Jamil, H.; Qayyum, F.; Cheikhrouhou, O.; Alassery, F.; Hamam, H. Optimal Scheduling of Campus Microgrid Considering the Electric Vehicle Integration in Smart Grid. *Sensors* **2021**, *21*, 7133. [CrossRef]
52. Szabo, J.; Fabok, M. Infrastructures and state building: Comparing the energy politics of the European Commission with the governments of Hungary and Poland. *Energy Policy* **2020**, *138*, 111253. [CrossRef]
53. Sulich, A.; Sołoducho-Pelc, L. Renewable energy procedures' strategies in the Videgrád group countries. *Energies* **2021**, *14*, 3048. [CrossRef]
54. Siddique, A.; Shahzad, A.; Lawler, J.; Mahmoud, K.A.; Lee, D.S.; Ali, N.; Bilal, M.; Rasool, K. Unprecedented environmental and energy impacts and challenges of COVID-19 pandemic. *Environ. Res.* **2021**, *193*, 110443. [CrossRef] [PubMed]
55. Rita, E.; Chizoo, E.; Cyril, U.S. Sustaining COVID-19 pandemic lockdown era air pollution impact through utylization of more renewable Energy resources. *Helion* **2021**, *7*, e07455. [CrossRef]
56. Hoang, A.T.; Nižetić, S.; Olcer, A.I.; Ong, H.C.; Chen, W.-H.; Chong, C.T.; Thomas, S.; Bandh, S.A.; Nguyen, X.P. Impacts of COVID-19 pandemic on the global energy system and the shift process to renewable energy: Opportunities, challenges, and policy implications. *Energy Policy* **2021**, *154*, 112322. [CrossRef] [PubMed]
57. Chomać-Pierzecka, E.; Sobczak, A.; Soboń, D. Wind Energy Market in Poland in the Background of the Baltic Sea Bordering Countries in the Era of the COVID-19 Pandemic. *Energies* **2022**, *15*, 2470. [CrossRef]
58. Juszczyk, O.; Juszczyk, J.; Juszczyk, S.; Takala, J. Barriers for renewable energy technologies diffusion: Empirical Evidence from Finland and Poland. *Energies* **2022**, *15*, 527. [CrossRef]
59. Shehhar, J.; Suri, D.; Somani, P.; Lee, S.J.; Arora, M. Reduced renewable energy stability in India following COVID-19: Insights and key policy recommendations. *Renew. Sustain. Energy Rev.* **2021**, *144*, 111015. [CrossRef]
60. Zakeri, B.; Paulavets, K.; Barreto-Gomez, L.; Echeverri, L.G.; Pachauri, S.; Boza-Kiss, B.; Zimm, C.; Rogelj, J.; Creutzig, F.; Ürge-Vorsatz, D.; et al. Pandemic, War, and Global Energy Transitions. *Energies* **2022**, *15*, 6114. [CrossRef]
61. Fei, L.; Shahzad, M.; Abbas, F.; Muqeet, H.A.; Hussain, M.M.; Bin, L. Optimal Energy Management System of IoT-Enabled Large Building Considering Electric Vehicle Scheduling, Distributed Resources, and Demand Response Schemes. *Sensors* **2022**, *22*, 7448. [CrossRef]
62. Muqeet, H.A.; Javed, H.; Akhter, M.N.; Shahzad, M.; Munir, H.M.; Nadeem, M.U.; Bukhari, S.S.H.; Huba, M. Sustainable Solutions for Advanced Energy Management System of Campus Microgrids: Model Opportunities and Future Challenges. *Sensors* **2022**, *22*, 2345. [CrossRef]
63. Muqeet, H.A.; Munir, H.M.; Javed, H.; Shahzad, M.; Jamil, M.; Guerrero, J.M. An Energy Management System of Campus Microgrids: State-of-the-Art Literature Review. *Energies* **2021**, *14*, 6525. [CrossRef]
64. Rasheed, M.B.; Javaid, N.; Ahmad, A.; Jamil, M.; Khan, Z.A.; Qasim, U.; Alrajeh, N. Energy Optimization in Smart Homes Using Customer Preference and Dynamic Pricing. *Energies* **2016**, *9*, 593. [CrossRef]
65. Deshwal, D.; Sangwan, P.; Dahiya, N. How will COVID-19 impact renewable energy in India? Exploring challenges, lessons and emerging opportunities. *Energy Res. Soc. Sci.* **2021**, *77*, 102097. [CrossRef]
66. Gebreslassie, M.G. COVID-19 and energy access: An opportunity or a challenge for the African continent? *Energy Res. Soc. Sci.* **2020**, *68*, 101677. [CrossRef] [PubMed]
67. Pietrzak, M.B.; Igliński, B.; Kujawski, W.; Iwański, P. Energy transition in Poland-Assessment of the Renewable Energy Sector. *Energies* **2021**, *14*, 2046. [CrossRef]
68. Gharavnidisi, H.; Ghafurian, R. Smart Grid: The electric energy systems of the future. *Proc. IEEE* **2011**, *99*, 917–921. [CrossRef]
69. Hamzaçebi, C. Forecasting of Turkey's net electricity energy consumption on sectoral bases. *Energy Policy* **2007**, *35*, 2009–2016. [CrossRef]
70. Tso, G.F.K.; Yau, K.K.W. Predicting electricity energy consumption: A comparison of regression analysis, decision tree and neural networks. *Energy* **2007**, *32*, 1761–1768. [CrossRef]
71. Produkcja Energii Elektrycznej W Polsce. Available online: https:///www.rynekelektryczny.pl/produkcja-energii-elektrycznej-w-polsce (accessed on 12 November 2022).
72. Korski, J.; Tabór-Osadnik, K.; Wyganowska, M. Reasons of problems of the polish hard coal mining in connection with restructuring changes in the period 1988–2014. *Resour. Policy* **2016**, *48*, 25–31. [CrossRef]
73. Mohideen, M.M.; Ramakrishna, S.; Prabu, S.; Liu, Y. Advancing green energy solution with the impetus of COVID-19 pandemic. *J. Energy Chem.* **2021**, *59*, 688–705. [CrossRef]
74. Szpor, A.; Ziółkowska, K.; The Transformation of the Polish Coal Sector. International Institute for Sustainable Development. 2018. Available online: https://www.iisd.org/system/files/publications/transformation-polish-coal-sector.pdf (accessed on 17 November 2022).
75. Emam, A. Present and future: Does agriculture affect economic growth and the environment in the Kingdom of Saudi Arabia? *Agric. Econ.-Czech* **2022**, *68*, 380–392. [CrossRef]

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Wind Energy Market in Poland in the Background of the Baltic Sea Bordering Countries in the Era of the COVID-19 Pandemic

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Abstract: The economic crisis caused by the COVID-19 pandemic reinforces the problem of rising electricity prices, which mainly affects countries that are forced to pay ever-higher CO_2 emission allowance fees (e.g., Poland). In the light of signals confirming the need for intensive development of the wind energy market in the Baltic Sea region, the authors consider the need to examine this issue concerning Poland and the Baltic States (i.e., Lithuania, Latvia and Estonia) as extremely important and demanding. The development of the RES market is currently an absolute necessity. The immediate neighbourhood and similar general social and economic conditions of Poland and the Baltic States enable factual comparisons, reinforcing the rationale for choosing the adopted research area. The main objective of the study was to assess the development of the wind energy market in Poland in the background of the Baltic Sea bordering countries in the era of the COVID-19 pandemic, in order to try to answer the question: what direction of wind energy development in Poland in the realities of the COVID-19 pandemic is justified and may have an impact on limiting the increase in electricity prices in this country? In this context, it turned out to be particularly interesting to identify solutions practised in the wind energy market in the Baltic States with their potential to be applied in Poland. The research instruments were drawn from an economic analysis and evaluation of phenomena and supported by the results of our own research (questionnaire) conducted on the Polish energy market, to substantiate the findings.

Keywords: energy market; renewable energy; wind energy; electricity prices

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1. Introduction

Rising prices characterise today's economic reality. Households, industry and services are being charged more for their utility consumption, in particular electricity and gas bills. The socio-economic situation has further been complicated by the coronavirus pandemic, reinforcing the burden on state budgets to fight the spread of the virus and the wide-ranging adverse effects of its effects. In addition, the unclear political situation in Eastern Europe increases the uncertainty as to the future of the energy market in this region, which is primarily powered by fossil fuels imported from the East—in the case of Poland [1], mainly hard coal from Russia, with a very significant scale of imports, exceeding the average annual amount of 8 million tonnes.

It must be emphasised that all fossil fuels are becoming scarce, thus their price on global exchanges is constantly increasing, entailing an increase in production costs [2] and, consequently, an increase in the sale price of electricity on the market. The scarcity of fossil raw material deposits, especially high-calorific ones, does not ensure energy security in the long term. Their processing generates pollution, mainly responsible for increasing climate changes [3], with irreversible consequences. The above motivates the world to tighten environmental policy in the area of energy production, increasing CO_2 emission allowance fees, entailing a drastic increase in the cost of energy production, which has affected Poland in particular recently, amplifying the crisis caused by the COVID-19 coronavirus pandemic through a significant increase in electricity prices. The above (leading) justifies and motivates the exploration of renewable energy issues, outlining the prospects of obtaining cheap, ecological electricity.

The renewable energy market is the most appropriate direction for developing the energy market. Energy obtained from wind or solar radiation, geothermal energy or energy obtained from currents, waves, tides, falling rivers or from biomass [4] is the most nature-friendly (climate-saving [5]) and necessary [6] formula for equipping the modern world with electric energy. As a rule, obtaining energy this way is free of the emission of harmful substances, including greenhouse gases [7]. The above is an important motivation for obtaining energy from alternative sources [8], creating a significant trend observed in the world. However, this development is important in various countries [9], including North-Eastern Europe. Different countries in this region implement solutions related to obtaining "green energy" to a different extent. There may be many reasons for this, including:

– Environmental and geographic conditions that give rise to or limit the applicability of a particular solution;
– The level of the greening of life and public education on the options available for obtaining energy and reducing the cost of its acquisition;
– The degree of motivation to undertake activities oriented towards acquiring energy from renewable sources, associated with clear and simple procedures for the construction of energy acquisition installations (the dimension of formal and legal regulations), together with financial support for their implementation and maintenance (subsidies, grants, tax exemptions, tax reliefs);
– Other.

The differences observed against this background are strongly marked globally, including in the Baltic region. The presented context highlights the need to recognise the current energy market situation in Poland and the Baltic States, as its stability determines the reality of the functioning of social and economic entities [10,11] in this region. Hence, the overall objective of the paper is to explore the progress of Poland and the Baltic States in implementing solutions oriented at obtaining energy from renewable sources. The immediate vicinity and similar geographical and environmental conditions of the countries adopted for the analysis ensure their comparability, potentially drawing on the results of the findings. The above justifies the outlined research context.

The main objective of the study was to assess the development of the wind energy market in Poland in the background of the Baltic Sea bordering countries in the era of the COVID-19 pandemic, in order to try to answer the question: what direction of wind energy development in Poland in the realities of the COVID-19 pandemic is justified and may have an impact on limiting the increase in electricity prices in this country? To this end, it is necessary to diagnose the current energy market situation in the Baltic Sea basin countries, with particular emphasis on wind energy as a potential for development of the "green energy" market. At the same time, an interesting thread of research is whether Poland—a country with a low level of drawing on RES solutions in the set of analysed countries—develops the wind energy dimension as strongly as solar energy [12] and what the prospects of its development in future periods are.

On a detailed level, the paper diagnoses the state of the electricity market in Poland and the Baltic States in the current economic conditions (including the impact of the COVID-19 pandemic on this market), outlines the essence of the wind energy process and exposes the economic conditions of this process.

However, the main research objective of this study is to try to find out what kind of renewable energy market development solutions—with particular emphasis on wind energy—can be introduced in the Baltic States, especially in Poland, to strengthen the local energy market and make a real contribution to lower electricity purchase prices.

The configuration of countries defined for this research also provides the possibility of multifaceted support for this research with published data available in industry reports from numerous sources.

The structure of this study includes:

- Part 1—introduction;
- Part 2—a literature review related to the economic background of wind energy market development worldwide;
- Part 3—research results in the area of the wind energy market in Poland and the Baltic States, including an assessment of its current and potential development directions;
- Part 4—discussion and conclusions.

The findings of this study are a fundamental contribution to the attempt to solve the problem of finding solutions for the development of the renewable energy market, with a particular emphasis on wind energy, which may realistically contribute to lower electricity purchase prices in Poland and the Baltic countries.

Despite the quantitative and spatial limitations of the study, the presented results give a significant view on the possible development potential of a cheap wind energy market in the studied area, providing a basis for further research and analysis.

2. Wind Energy in the Global Energy Market—Literature Review

2.1. Wind Energy as a Global Energy Market Direction—Empirical Findings

There are numerous publications in the literature on RES, but bibliometric research has revealed that only 12.76% of them deal with wind energy [3].

Energy demand in the world is increasing, from the strong development of the infrastructure of cities, transport and broadly defined services [13–15]. The stability of the energy market assumes an increasing importance for the undisturbed functioning of societies and the continuous development of world economies [16]. It is worth noting that this trend has been reinforced by the outbreak of the COVID-19 coronavirus pandemic, articulating "remote working", "remote teaching" and "remote consumer behaviour" and reinforcing electricity consumption.

The literature provides many analyses on the issue of the influence of energy conditions on the functioning and development of economies [17]. The cost of energy purchase plays an important role in shaping the structure of household budgets and strongly influence the cost of production of goods and provision of services, modelling the strength of the economic cycle. The above motivates the search for solutions giving the possibility to obtain cheap energy, stabilising the realities of functioning in the light of energy security [18]. In this regard, the RES market offers many solutions that constitute an alternative to the perspective of capital-intensive energy import [19], the choice of which is conditioned by the appropriate resources of renewable sources in the area creating the energy demand, which is the key justification for undertaking specific challenges with economic effects.

The shift in consumer preferences towards "green energy" observed worldwide results in a growing demand for it and an increasing trend in the development of the RES market [20], as a widely recognised alternative to conventional sources of energy generation [21]. However, does the scale of this development match the degree of increasing demand for energy from renewable sources? What economic aspects are associated with this course of action? These issues are of particular importance in countries that are generally dependent on energy generation based on classical solutions [22] (e.g., Poland [23]). The cost of energy production based on traditional solutions is shaped not only by the increase in the prices of energy-bearing fossil fuels and capital-intensive production technology, but additionally burdened with significant (increasing) environmental charges, including, among other things, the rights to emit carbon dioxide into the atmosphere in connection with the production performed, which in Poland currently exceeds EUR 20 billion. The above should also include the financial burden of damages caused by the implementation of traditional manufacturing processes (e.g., EUR 45 million to the Czech Republic for the operation of lignite mines and the Turów power plant in Poland, as compensation for the outflow of underground water from the national territory, air pollution, dust emissions and noise). Efforts to reduce the negative effects of traditional electricity production, leading to a strongly increasing market price of electricity per 1 kW, are determined by the adopted direction of the energy policy of countries [24], which, to varying degrees, open themselves to sustainable development [25,26] and follow the technological thought, in this field with a strong environmental and economic justification.

The literature highlights the global development of the renewable energy market [22] and the growing interest in RES solutions. Wind energy is particularly interesting [27], and is recognised as an important energy source [3]. This position is supported by the fact that wind energy reached 1590 TWh in 2020, accounting for 5.9% of the global electricity demand. China was the leading producer of wind energy in 2021 (half of the global capacity). Among European countries, Denmark (49.7%), Ireland (22.9%), Portugal (22.3%) and Spain (17.7%) achieved the highest share of wind energy in their national energy production [28]. The total global wind power capacity currently reaches 743 GW, affecting the unit price of power purchase and reducing CO_2 emissions to the atmosphere at the level of 1.1 billion tonnes of CO_2 [29]. The offshore wind energy market development is particularly noteworthy in the global wind energy market, with its global active capacity currently exceeding 50 GW, reaching a 0.3% share in the global energy supply.

The presented stage of the literature review confirms the strong development of the wind energy market in the global energy market. World powers and European countries are analysed and evaluated—in particular leaders in selected areas of the energy market or selected performance of particular countries together—mainly to determine their places in the ranking of results. In the authors' opinion, insufficient research has been carried out on Poland compared to other countries from its environment, i.e., Central and Eastern Europe, hence the inspiration to take up the issue specified in the paper's objective. The above is particularly important as the analysis of solutions applied in the economic practice of the Baltic countries may provide a stimulus for the development of the wind energy market in Poland; on the other hand, the analysis of solutions applied in Poland may be useful for modelling energy policy in the region.

The above reinforces the rationale for the analytical direction adopted in this study, focused on identifying this dimension of the energy market in the RES market, and this choice is reinforced by the results of the Sustainable Development Report 2019, Transformations to Achieve the Sustainable Development Goals [30], revealing the places of the analysed countries in the ranking of 193 UN members on the implementation of the Sustainable Development Goals by 2030 (including the green energy index), where Estonia is ranked 10th, Latvia 24th, Poland 29th and Lithuania 32nd (the authors were not able to determine the ranking in this respect during the COVID-19 pandemic).

2.2. Economic Background of Wind Energy in the Global Energy Market—Theoretical Findings

The issue of substantive and economic justification for implementing wind power projects is a constant point of analyses and discussions in the literature, as the primary motivation for undertaking any investment activity is the widely considered issue of cost optimization. The background of economic justification of investment activities undertaken on the wind energy market determines the efforts focused on increasing the efficiency of existing solutions in this area. Hence, this theme is present in the following part of the literature review, the purpose of which is to outline the essence of wind energy and articulate important determinants of wind installations, which in effect determine the cost of access to cheap electricity from the source in question. This is a particularly important consideration in the era of the COVID-19 pandemic.

2.3. Energy from Wind Is Created Based on the Wind Energy Conversion Factor (VSCF)

The most commonly used solution in this area is the use of a doubly fed induction generator (DFIG) and permanent magnet synchronous direct-drive generators (PMSG) [27]. These are the most popular wind energy conversion systems, the essence of which is created by the process of converting mechanical power from the wind turbine to alternating electric current, which, with the use of a converter (with a dc link), is converted to direct current, which in turn, with the inclusion of an additional PMSG inverter, can generate direct current with a voltage and frequency that allow the plugging into the grid [27]. However, integrating wind power into the power system implies many challenges. These include the problem of subsynchronous resonance (SSR), whose induction is derived from the wind turbine being connected to a series-compensated transmission line, or the provision of low-voltage ride-through (LVRT) [31]. Adaptability to wind speed is an important aspect determining the cost of construction and maintenance of a wind installation (turbine selection). The construction of transmission lines and energy storage facilities creates the remaining main costs, giving an average investment per megawatt-hour of just over EUR 40 [29]. However, attention should be drawn to the fact that the market turmoil caused by the COVID-19 coronavirus pandemic may contribute to a correction of the indicated price ranges.

Wind power is a key determinant of the efficiency of a wind installation. It is essential to characterise its strength in the field (mapping the geographical distribution of the wind resource potential [32]) in connection with the planned construction of a wind unit in order to relate the actual wind resource conditions to the installation parameters (turbine power [33]). This task is difficult, usually requiring many years of measurements and analyses, often regarding probability density functions (PDFs) [34]. Improving NWP+ML models for wind power prediction is becoming important [35–39]. The analysis of wind speed and wind power density distributions provides a basis for determining indices for selecting turbine power [40] under their planned performance. This is necessary to ensure the output and high quality of the electricity [19] (e.g., without voltage fluctuations [41]). At the same time, it is important to ensure a smooth operation of the system, minimising turbine outages and limiting the occurrence of mechanical stresses, which increase maintenance costs. The above reveals the relation between the maximum energy obtained from the wind and the cost of maintaining the installation [31]. Capital-intensive solutions to the overproduction of electricity and the need to store or dispose of surpluses cannot be ignored.

In order to maximise the use of energy obtained from wind and increase the economic effect of projects related to wind installations, it is justified to monitor system power points (MPPT) based on the control of the inverter connected to the generator. In this respect, the literature points to several methods [27,42–44]:

- Power feedback control MPPT;
- Fuzzy-logic-based control MPPT;
- Optimum tip speed ratio control (TSR MPPT);
- Hill climb searching control (HCS MPPT);
- Other.

Through the prism of optimising the efficiency of wind power installations, the above determines their effectiveness, increasing the economic justification of projects related to the acquisition of energy from wind. However, at the basis of the efficiency of wind installations lies the issue of the positioning of wind turbines strictly concerning wind resources and not in relation to the aesthetic value of the installation's setting in its surroundings [45], which is all too often noted in practice (in particular in cities). In this respect, the level of knowledge on available wind energy resources and their stability is important. Scientific positioning of installations is an expensive undertaking, based on long-term and capital-intensive tests [46]. It is crucial to reduce the capital-intensive failure rate of wind farms, subject to the influence of highly turbulent flows from waves in the wind installation [47] or ambient turbulence [48].

The choice of the right one out of the available directions for "green energy" is facilitated by energy research. It provides a basis for modelling sustainable energy generation and energy management solutions, which, as a rule, involve a technological revolution requiring significant capital expenditure to construct energy generation and storage facilities.

The demanding area in this respect is the random energy carrier. The measurement and proper selection of the parameters of a wind installation assume a critical importance for its efficiency, determining the return on capital over the assumed period [49,50]. However, the risk of estimation error here is significant due to the variable nature of the resource. However, given the steady increase in conventional power generation costs, the economic justification for undertaking wind energy production should be continuously increasing, considering the risk dimension outlined.

The presented literature review outlines the economic background of wind energy in the global energy market, indicating the importance of the problem for the cost potential of wind energy. Only an economically viable solution in wind energy can contribute to the cost-effective production of 1 kW of electricity through the conversion of wind kinetic energy. A complete knowledge in this area will provide the fullest possible view of the problem. It will provide the basis for reliable cost calculations, enabling the modelling of the payback period for an investment in a wind energy installation, in line with the profitability calculation model (rate of return), which assumes a particular importance in times of crisis caused by the COVID-19 pandemic.

3. Materials and Methods

The search for answers within the scope of the defined theses required the observance of the principles of comprehensibility of the research process and its relevance to information needed to interpret the analysed phenomena and predict their development properly. Hence, in the introduction to the paper, the conceptual dimension of the research was defined—it assumed an empirical and analytical character. The core of the research is the analysis of industry reports from the energy market in Poland and the Baltic Sea Region countries (Lithuania, Latvia and Estonia) adopted for the analysis and statistical reports and studies prepared at the level of individual countries and the European Union. At the same time, methodological limitations should be mentioned, resulting from potential differences in determining certain economic categories, which are the input data to the analyses (e.g., source material in the form of reports). The study was also based on our own research results concerning the diagnosis of wind energy development potential in the Polish energy market. Due to the order of evaluation of the problem studied in the study, the following methods were applied:

- Deductive (fragmentation), growing out of a thesis formula based on synthetic results, allowing for a search for causes and effects in order to identify them in detail;
- Inductive (fusion), which allows the exploration of individual themes and their subsequent generalisation in the form of conclusions and evaluations.

The above simple methods of analytical procedure were applied to a number of research dimensions undertaken in this study.

The research included situational and comparative analysis methods. In the analysis of trends in the development of phenomena, techniques specific to the prediction of phenomena were applied. The layout of the research was systematised in the algorithm below (Figure 1):

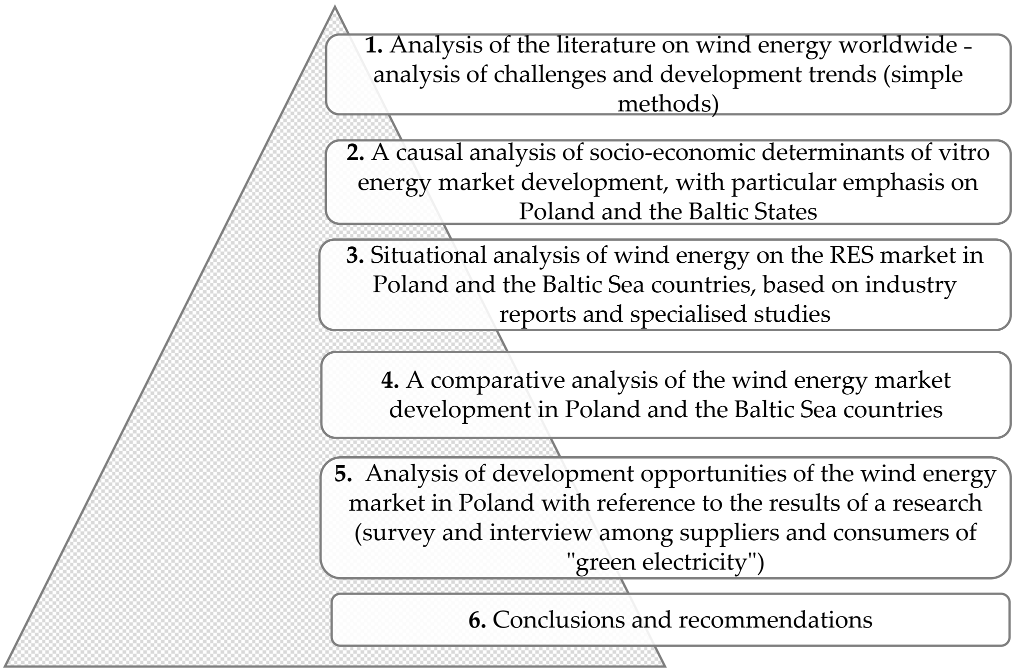

Figure 1. Research algorithm.

The literature research was based on numerous national and international industry studies, considering the most recent research on the subject. Particular attention in the world literature analysis was paid to considerations related to the wind energy market, considering its current development trends. The content analysis was critical of current solutions in increasing the operational efficiency of wind energy installations, which strengthen the economic justification for their construction.

The literature on wind energy is quite extensive. It presents numerous solutions concerning wind power installations' technical and economic aspects. The importance of the subject matter for the development of economies has been emphasised. There is, however, a lack of appropriate studies at the level of individual countries, including a significant topic for the authors, i.e., the assessment of development prospects of the wind energy market in Poland in the realities of the global energy transformation. The above justifies the choice of the topic and the instruments used to explore it. Hence, the research was based on international professional literature comprising articles and scientific studies, including international reports, forecasts and estimates.

The authors have dealt with the key trends and issues in the research, allowing the analysis of experiences on a global scale, in comparison with the experiences of the Baltic States and Poland, to answer the questions posed in the study. In this respect, a critical analysis of the current situation was carried out, taking into account the findings of our own research (interviews with selected companies from the energy sector—RES branch) to create reliable conclusions. In order to reliably assess the prospects for the development of the wind energy market in Poland, the results of our own research, "Effectiveness of offering—RES" (analysis of questionnaires and opinions of customers and potential customers of a major wind energy design company in Poland, November 2021) were used. Moreover, the results of this research dimension made it possible to define recommendations that added value to the findings.

The authors' primary objective is to deepen the knowledge taking into account the results in the field of green energy, to use it in the definition of a model for wind energy solutions tailored to the realities of the Polish economy and the countries of the Baltic Sea basin. The above serves as a basis for modelling wind energy development plans and further research, broadening the spectrum of data and allowing for reliable modelling forecasts.

4. Results

4.1. Determinants of Wind Energy Market Development in Poland and the Baltic States

The main justification for implementing renewable energy solutions is the rising cost of conventionally produced electricity. This cost assumes a particular importance in the economic dimension in the era of the COVID-19 pandemic, contributing to price increases that financially hit society and business. At the same time, the social dimension is important, in the form of a negative impact on the environment (emissions, discharges, noise) with continuous deterioration of the quality of life in a polluted environment. Essential for investment activities in the field of RES are economic conditions of the outlined phenomena, directly related to the price of electricity, which, from 2019 through 2021 in specific tariff groups, increased for Poland (+10.6%) and Lithuania (+3.1%), and was adjusted downwards (reduction) for Latvia (−3.35%) and Estonia (−7.5%) [51].

The average purchase price of electricity of Poland and the Baltic States at the turn of the year 2021 and 2022 reached an average level of EUR 0.145/kWh. The detailed distribution of prices per 1 kWh from January 2019 to the beginning of January 2022 in Poland and the Baltic States is presented in Table 1.

Table 1. Average electricity prices per kilowatt-hour from January 2019 to early January 2022 in Poland and the Baltic States [52].

	Average Electricity Price in the Period 2019–2022 EUR/kWh (Month/Year)			
	January–December 2019	January–December 2020	January–June 2021	December 2021–January 2022
Poland	0.14	0.15	0.15	0.17
Lithuania	0.12	0.13	0.13	0.14
Latvia	0.16	0.14	0.14	0.14
Estonia	0.14	0.13	0.13	0.13

The above reveals higher electricity purchase prices in Poland than the Baltic States analysed, by 17.2% on average. Hence, it is reasonable to carry out a more detailed analysis of the burden structure of electricity price increases in Poland in the period 2019–2022 (Figure 2).

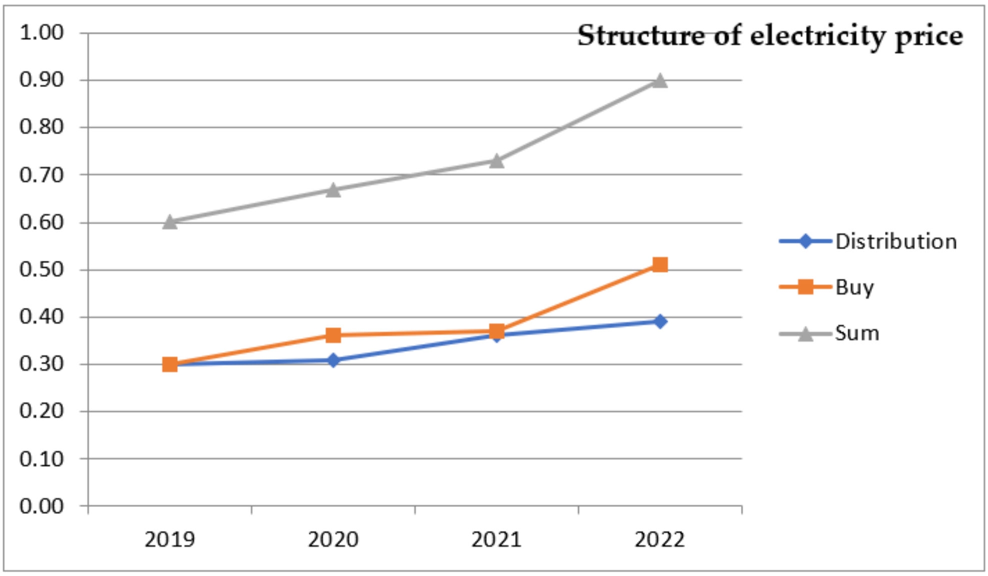

Figure 2. Analysis of the burden structure of electricity price increases in Poland in 2019–2022 [53].

The effects of the significant increase in electricity purchase prices in Poland from January 2022 were amortised by a reduced value-added tax rate from 23% to 5% [53].

The analysis of detailed parameters of electricity price increases for end consumers, by tariff group, carried out by the leading electricity supplier in Poland in February 2020–February 2022, revealed the values shown in Table 2.

Table 2. Electricity price increases for end consumers of the leading electricity operator in Poland, by tariff group, in the period February 2020–February 2022 [54–58].

Segment	Tariff Group	Tariff	24 h Gross Commercial Service Rate (EUR/MWh)				
			Value Change (Month/Year)				
			From February 2020	From July 2021	From November 2021	From January 2022	From February 2022
			EUR/MWh				
BIG BUSINESS	Mega business	A21	90.3	99.4	114.2	140.5	189.7
	Business	B21	90.3	99.4	114.2	140.5	189.7
	Standard	B11	93.9	103.3	118.7	143.6	193.9
MEDIUM BUSINESS	Company	C21	0.09	0.10	0.12	0.14	0.19
SMALL BUSINESS	All day	C11	0.09	0.10	0.21	0.14	0.20

Segment	Tariff Group	Tariff	24 h Rate for Commercial Service			
			Gross (EUR/MWh)			
			Dynamic of Price Changes (Month/Year)			
			February 2020–July 2021	July 2021–November 2021	November 2021–January 2022	January 2022–February 2022
			EUR/MWh			
BIG BUSINESS	Mega business	**A21**	+9.09%	+13.01%	+18.70%	+25.9%
	Business	**B21**	+9.09%	+13.01%	+18.70%	+25.9%
	Standard	**B11**	+9.08%	13.01%	18.70%	+25.9%
MEDIUM BUSINESS	Company	**C21**	+6.86%	+12.8%	+17.60%	+26.04%
SMALL BUSINESS	All day	**C11**	+16.8%	+49.5%	−43.24%	26%

The elements of the current price structure adopt the following relationships:

- Cost of electricity generation;
- Distribution cost;
- Cost of CO_2 allowances: 22.61%, with calculations of 59% being encountered;
- Transition charge;
- Cogeneration charge;
- RES charge;
- Power fee;
- VAT.

The expiry of the Electricity Pricing Act, which was in force until the end of 2019, contributed to a severe price increase from January 2020. During this period, the charges for daily CO_2 emissions started to increase dramatically from the previous level oscillating around EUR 30/ton in January 2020, through a level in the range of EUR 60/ton in December 2020, to a level exceeding EUR 85/ton in December 2021. This mechanism has directly shaped the currently quoted electricity price level.

Against the background of the analysed group of countries, Poland had the highest electricity price increase, although compared to the European average, this result did not look too bad—Figure 3. Unfortunately, the Energy Regulatory Office forecasts in Poland do not reassure consumers. Further increases in energy production costs and distribution prices are expected.

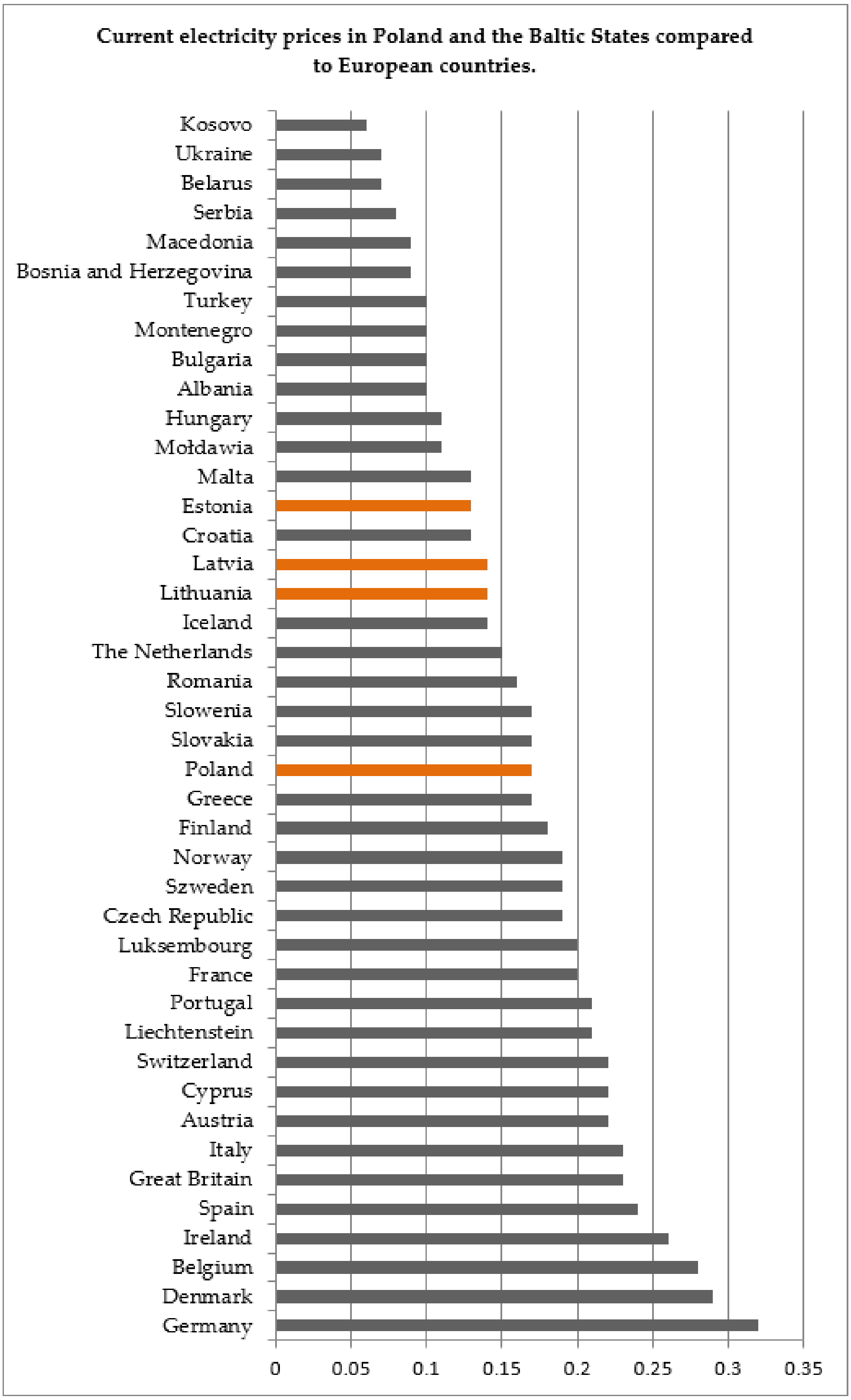

Figure 3. Current electricity prices in Poland and the Baltic States compared to European countries [51].

Another factor contributing to the global increase in electricity prices is the random factor of the COVID-19 coronavirus pandemic. The negative economic impact of this condition can be attributed to temporary restrictions on the extraction of fossil fuels and rising material costs, disrupted supply chains, production and shipping processes—due to business restrictions, up to and including lockdowns. At the same time, the trend in electricity demand continues. This background draws a strong demand for energy from renewable sources, which takes the largest fixed share of the energy system with the lowest variable costs, ahead of nuclear power plants, but above all of the least economically viable coal-, oil- and gas-fired power plants. In modern energy policy, the share of the latter is assumed to be complementary to the RES and fission energy base in production processes, whereby high energy demand results in their continuous integration into production processes. In this way, cheap energy from renewable sources is increased by the actual cost of producing "expensive electricity", shaping the current market price of purchasing 1 kW—Figure 4.

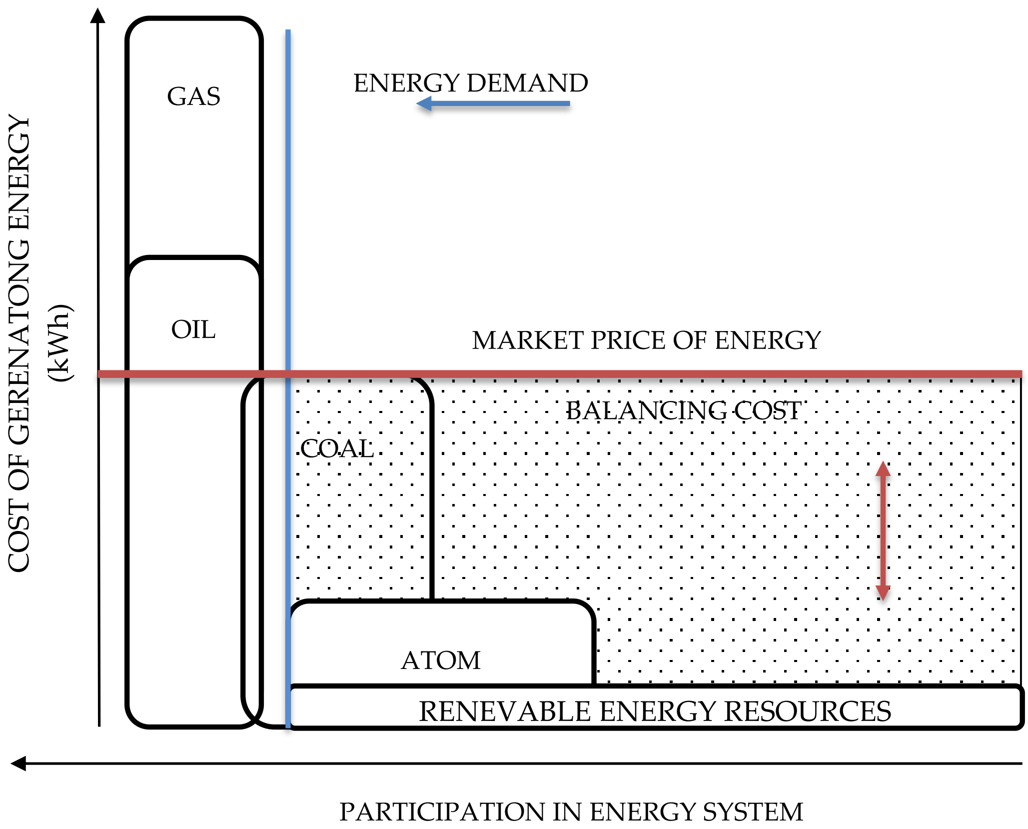

Figure 4. Electricity price structure [59].

The analysed model of the energy system illustrates the necessity and economic justification for taking actions aimed at strengthening the share of RES solutions in the overall energy system, and the observed upward trend of components creating the structure of electricity prices in Europe strongly motivates to take action.

Considering the discussed topic at the level of the Baltic Sea states adopted for the study, a significant importance in the modelling of energy supply solutions can be attributed to the uncertain policy of the East. It is worth noting that on 8 and 11 April 2021, Lithuania was cut off from energy supply from Belarus, while Latvia stopped importing energy from Russia. Hence, in December 2021, during the Baltic Council of Ministers with the participation of the heads of government of Lithuania, Latvia and Estonia, the direction of achieving energy independence and national security of the region by plugging into the electricity system of the continental European grid in 2025 was confirmed, as well as the need to increase electricity production in order to reduce its prices. The argumentation cited in the paper indicates that the most appropriate direction for strengthening the energy base is the RES market, hence the expectation that the countries of the Baltic Sea Region will also follow this direction. The above expectation has turned out to be fully justified, as the Baltic Sea countries are strongly investing in a green energy industry strategy, including solutions oriented towards the conversion of the kinetic energy of moving air masses into electricity, using wind turbines. The benefits of these installations are tangible. According to the latest reports (8 February 2022), the January wind contributed to lower electricity prices in all the countries of the Baltic Sea basin, where wind installations are important in the overall energy system. The above is expected to reduce electricity prices month-on-month in Lithuania (−31%) and stabilise relatively favourable electricity prices in Latvia and Estonia. This is an important argument confirming the rightness of making efforts for RES development, with a particular emphasis on wind energy in the Baltic Sea region analysed.

4.2. Analysis of the Wind Energy Market in Poland and the Baltic States

The wind energy market in Poland and in the countries around the Baltic Sea is developing rapidly. In Poland, where the dominant power sources in the energy mix are coal and lignite, the capacity of installed onshore wind installations in 2020 reached 6.35 GW, and in 2021, the electricity production from renewable RES sources were nearly 28 TWh, where almost 16 TWh (57.14%) came from wind energy [29] (the share of RES in the total electricity production in Poland in November 2021 was 15%). The above indicates that wind energy may be an important link in transforming Polish conventional energy into an environmentally friendly (clean) and attractive (cheap) one for consumers. The restriction in the development of wind farms in the period 2017–2019 (with 2017 dynamics to 2018: 0.7%, 2018 to 2019: 1.01%, 2019 to 2020: 6.77%) was triggered by unfavourable formal and legal regulations ("Distance Law"), defining minimum distances from buildings (10 times the height of the installation), which the wind energy sector expects to be liberalised (abolition of the 10H rig), in order to enable the implementation of projects related to its development in Poland, through the construction of technologically advanced, economically efficient farms. With the revision of the regulations announced for this year, the construction of new onshore installations could be launched as early as 2024. The current regulations encourage the search for solutions in offshore wind farms. The potential of the Baltic waters in this respect is immense, as the farms currently operating in this territory provide only 2.6 GW, with a diagnosed potential by 2050 of 90 GW [60]. According to "Poland's Energy Policy until 2040", in 2030, Polish wind energy will continuously increase its capacity and, through investment, the first offshore wind farms are to be commissioned in 2024. The year 2040 is to be characterised by 11 GW [60] of capacity. Such a strong development must be ensured by basing the domestic RES energy market on wind energy [61]. The resilient development of this energy sector in Poland attracts the attention of neighbouring countries as more and more countries in the Baltic Sea region are interested in Polish wind energy companies, particularly Lithuania.

Lithuania's share of renewable energy production in the energy balance of the European Union already reached an impressive 80% in 2019. Lithuania's further efforts in the sphere of RES strengthening are evident. The development of wind energy is progressing gradually. The total capacity of wind power plants has reached 400 MW, of which 25% is the power generated from the installations put into operation during the pandemic (2021).

In Lithuania, similarly to Poland, a significant attention has been focused on offshore wind energy. Analyses of the potential of offshore wind farms in the Baltic Sea are being carried out, and their capacity is estimated to be 700 MW, which from the supply side gives 2.4–3 TWh of energy potential, with the capacity to secure at least 25% of Lithuania's electricity demand. Importantly, offshore wind farms are expected to power Lithuania's grid by 2030.

Wind energy development is currently a priority in Lithuania, related to strengthening energy independence. This is a very important topic, as 60% of the energy needs in Lithuania are secured through imports.

The Latvian RES market is created by hydropower and biomass plants and a wide potential of wind energy, creating the share of renewable energy in the EU balance at the level of 35.2%, giving it the third position among the EU countries. Riga decision makers plan to gradually expand the share of wind technologies in the adopted energy policy and gradually move away from basing electricity production on firewood. According to Latvia's assumptions and climate aspirations, the share of RES in the total national energy market is to reach a level of up to 55% by 2030. In order to realise the above, Latvia has limited the financing of investments based on fossil fuels or natural gas, while introducing an attractive system of tax incentives, orienting the development of the sector towards clean energy. Wind energy plays a particularly important role in this sphere, with a potential demand for about 500 MW of generating capacity, in order to achieve the assumed goals of improving energy efficiency in this country.

The RES market has been strongly established in Estonia. The raw material most heavily used in energy production there is high-carbon bituminous shale, whose energy production, as recently as 2018, accounted for 70% of the market share, overtaking the energy supply of biomass resources, where greenhouse gas emissions from shale energy production took 90% of Estonia's total emissions volume. The above has prompted the search for alternative energy sources.

In 2018, 1665 GWh of electricity was obtained from renewable sources in Estonia, which represented a 17% share in the energy mix. In 2020, the level of RES in the total gross consumption had already reached 30%. Perhaps the resilient development of this market is determined by the essential participation of the Estonian State Treasury companies in the structure of the sector's entities, together with the system of incentives in connection with offering certified ecological packages.

An increased demand for green energy results in increased RES activities in the studied region. The above results in interest in wind energy potential obtained at sea [62–64] (the Baltic Sea), a strongly growing source of renewable energy [65,66]. This creates opportunities for an intensive development of Poland and the Baltic States in wind technologies, contributing to the planned reduction of greenhouse gas emissions and increasing the economics of wind power generation, determining the market price of electricity. Dynamic wind energy development is hampered by current, often underdeveloped, formal and legal regulations. The above refers in particular to innovative solutions undertaken for the first time at the level of individual economies, such as challenges in the sphere of innovative offshore wind farms in Poland.

The capacity of the energy systems of individual states is in the interest of neighbouring countries. The degree of energy security of the region is determined by the dimension of international cooperation on the issue of connection to general wind systems and cross-border cooperation in the sphere of energy exchange and supply. In this respect, the strongest field of cooperation is seen in the wind energy of the Baltic Sea states.

Latvia and Estonia cooperate on offshore wind energy by working on wind solutions in the Gulf of Riga. More intensive wind energy development in the region calls for cooperation between Poland, Lithuania, Latvia and Estonia [67]. In the total offshore wind potential of the Baltic Sea (93.5 GW), Latvia has the highest share of 15.50% with 14.5 GW of installed capacity and Lithuania has the lowest share with 4.8% and 4.5 GW [68]. The detailed distribution of shares in the potential in question is presented in Figure 5.

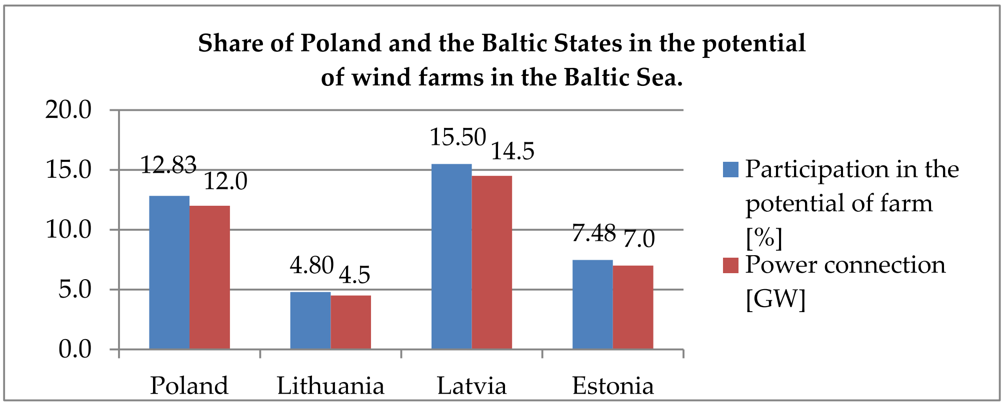

Figure 5. Share of Poland and the Baltic States in the potential of wind farms in the Baltic Sea [68].

This requires investment in the infrastructure necessary for the production and trade of energy, which is nowadays connected with a system of efficient, intelligent and cyber-secure networks. This dimension of investments is to be substantially fuelled by the European Union, focusing on the development of infrastructure for network connections between countries across the Baltic Sea. The potential of the sea is a key instrument in reducing CO_2 emissions, according to the European Green Deal [69]. Importantly, these tasks are carried out in the reality of the COVID-19 pandemic, taking into account the risk of changing unit prices for the implementation of activities

4.3. Analysis of Wind Energy Market Development Potential

Wind energy is a source of cheap, clean energy, whose share in the energy mix contributes significantly to reducing electricity purchase prices. As a rule, wind power plants are technologically advanced and costly solutions, most often with significant connection capacities, referred to as investment projects undertaken by market players. However, wind power plants, similarly to photovoltaic installations, may have a diversified character determined by their energy potential, and their application may be practised both at the level of strategic units and institutional or individual consumers. A literature review on the subject reveals scarce discussions on small wind installations dedicated to individual consumers. The results of our research, "Effectiveness of offering—RES" (an analysis of questionnaires and opinions of customers and potential customers of a major company designing wind installations in Poland, November 2021), confirm a significant lack of knowledge about the possibilities of using small wind power installations (48% of respondents) and about the types of solutions available on the Polish market (73% of respondents), while revealing a potential interest in the subject (93% of respondents).

Therefore, it is worth noting that several photovoltaic solutions are of different capacities, dedicated to individual consumers and companies. Among them, the following ones stand out:

(a) Advanced solutions, with connection powers from 8 kW to 30 kW:
- Fully automated in controlling the operation of the wind generator;
- To support the supply of power to the facilities;
- With the possibility of connection to the power grid.

(b) Small domestic solutions of 0.5–5 kW:
- To support the supply of power to installations, consumers;
- With the possibility of backing up with mains power on windless days to ensure continuity of the energy supply (minimum power).

(c) Small wind power installations of 0.1–1 kW:
- To complement the energy potential of the facility;
- For the point supply of selected consumers.

These installations are in the form of classical windmills, horizontally—horizontal axis wind turbines (HAWT), or in turbines with a vertical, noiseless axis of rotation—vertical axis wind turbines (VAWT)—Świder, drum and other. The type and size of the installation is determined by its power and the requirements for the foundation (permanently fixed to the ground on a foundation footing, on a free-standing mast, on the roof of a building). Large installations in this category of wind turbines have a rotor diameter greater than 3 m, a power output greater than 2000 W and a generator weight greater than 200 kg. Small installations belong to the solutions group with parameters lower than those mentioned above. Small wind installations are also equipped with batteries with a dc/ac converter, heaters with a controller (water, central heating), an on-grid converter giving the possibility of electricity resale to the power grid, integration with mobile communication devices for analytical purposes, etc., therefore increasing their functionality, which creates their market attractiveness.

It is estimated that small wind installations are two to three times more efficient than photovoltaics—the average annual electricity production from a 15 kW turbine is about 31,000 kWh. The most popular installations in Poland are microinstallations with a capacity of 3–5 kW. The installation on a residential building does not require any permits (apart from a height restriction of 3 m relative to the roofline), which provides considerable freedom of operation. However, it should be noted that free-standing installations are subject to certain restrictions. The cost of a wind installation depends on the connection capacity. The solutions adopted currently vary between about EUR 5000 for a 3 kW installation, about EUR 8800 for a 5 kW installation, and about EUR 1700 for a 10 kW wind installation.

By mid-2021, below 80 micro wind installations with a total capacity not exceeding 0.4 MW had been built in Poland, representing only 0.05% of all RES microinstallations. The availability of information in relation to the development of micro wind power plants in the Baltic States is negligible, which may mean that, as in Poland, their installation is not very popular. This situation may change with the development of commercial wind farm installations and information on their performance. Polish companies operating in the wind energy sector have announced the promotion and sale of Polish micro wind products in Lithuania and Estonia. The micro wind market is still the future, both in Poland and in the Baltic States, although the above may herald an increased interest in developing the small wind market. The lack of an appropriate information and promotion campaign and a support programme motivating to invest may directly cause the observed state of affairs.

Wind conditions in Poland anchor the potential for developing this wind energy direction and in the Baltic States provide a good potential for the development of projects of this type. In Poland, most areas have relatively favourable wind conditions. An average of 250 windy days per year is recorded with an average annual wind speed of 2.8–3.5 m/s, which creates conditions for good performance of wind power installations. This potential must be exploited. This is an important direction of action to reduce the purchase price of electricity by individual consumers or small businesses.

The appropriateness of micro wind development is further confirmed by the results of the referred studies, which show that:

(a) Around 71% of consumers who purchased micro photovoltaic installations were interested in extending them with wind installations;
(b) Around 47% of the potential consumers, responding to a market survey of the RES microinstallation market, indicated wind microinstallation as a potential direction of their future choices, with the majority of respondents indicating wind energy (at the discussed level) as a complementary source of electricity, i.e., in combination with other RES installations—photovoltaics, heat pumps, recuperation);
(c) In terms of interest in the type of wind installation, respondents interested in wind energy indicated:
    - Small microinstallations 3–5 W, with an option to install them on building structure: 53%;
    - Stand-alone solutions not exceeding 10 kW: 11%;

- No choice was indicated for 36% of respondents.

(d) Around 14% of respondents were willing to consider investing in a wind installation in the near future,
(e) Around 32% of respondents had no opinion on the possible need for investment in wind energy,
(f) Around 7% of respondents were not interested in a wind installation.

The presented research results indicate a significant potential for developing the wind microinstallation market in Poland. In this regard, it seems necessary to undertake actions towards:

(a) The promotion of knowledge about wind installations in the subject:
   - Types, power, purpose, functionality, etc.
   - The impact of wind turbines on the surrounding area, as concerns about general safety have been revealed (research results), the impact of magnetic fields on users and their surroundings, noise emissions—including reference to acceptable standards—other potential nuisances in connection with the installation;
   - Maintenance of installations in the long term, combined with efforts to provide professional advice.
(b) To improve the range of available products due to the visual aspect of solutions, allowing the installation to be integrated into an attractive building envelope or stylish backyard garden.

When considering the above, one cannot forget about the key determinant—the financial incentive to undertake such challenges, adequately communicated to the recipients' potential. Although this theme was not revealed in the study, in the opinion of the study's authors, it cannot be omitted in any way.

The interest in micro wind installations is a very good sign. The development of wind energy may contribute to the expected improvement of financial conditions for the purchase of electricity on the market and climate impact parameters in connection with the ambitious global goal of achieving climate neutrality. Implementing mass green solutions, including micro wind power installations, is an excellent step towards strengthening proenvironmental measures [70] and making long-term environmental goals more credible [71].

5. Discussion

The results of the considerations presented in this paper indicate that the development of wind energy in Poland and the Baltic States is the right direction to strengthen the RES sector.

The main conclusion from the conducted research confirms the validity of the adopted direction of development of the RES market in Poland and the Baltic States, taking into account arguments of social and economic nature. A socio-economic justification for the development of the wind power sector emerges against the background of the EU energy policy, coupled with the conditions for the possible development of individual economies and the costs of achieving the adopted targets.

Summarising the findings, it should be pointed out that the initial data from the analysis of the wind energy sector in Poland and the Baltic Countries confirmed the observed general trend of development of the market in question towards offshore wind farms. An analysis of socio-economic conditions leads to believe that the adopted direction of actions will be successful in terms of RES strengthening in the studied area. It has been revealed that spectacular investments in terms of technological advancement and costs have overshadowed the promotion of simple wind solutions (microinstallations), the launch of which, e.g., in a number analogous to that of photovoltaic installations, would provide effective support for the implementation of the EU Green Deal policy and would significantly reduce the cost of 1 kW of energy for end consumers. The above may serve as an inspiration for strengthening activities to promote the (informational and financial) energy generation from wind. The above refers particularly to the Polish market, where the share of RES in the national energy system is the lowest among the analysed countries, which results in higher electricity prices expressed in the growing market price per 1 kW of electricity. The analysis of the results of our own mentioned research confirmed the existing potential for developing the mini wind energy market in Poland (93% of the respondents), together with the arrangement of the basic activities expected by the market in this respect. Therefore, investments in micro wind installations, carried out on a broad scale, may contribute to a real reduction in the cost of electricity for domestic consumers. Rapid implementation of the above is possible in the light of favourable aid solutions, which should be correlated with the adopted environmental policy. The system of incentives (subsidies or tax deductions) has created the strong development of photovoltaic installations in Poland and in the Baltic Sea countries studied. It is worth paying attention to this dimension of support in order to repeat this success.

Public support for wind farm development in Poland is very important. This is confirmed by the results of the conducted surveys. Therefore, the expectation of wind farm development in Poland may be associated with an urgent need to amend the existing distance law (10 H), which significantly limits the development of onshore wind energy in Poland. The above constitutes an important conclusion and recommendation of this research.

The area of the formal and legal framework and possible sources of support for the implementation of investment activities in wind installations is a research topic that requires a separate study. The justification for the above are, among others, the revisions of existing regulations in this area announced this year. The above creates an important research problem that provides a basis for revising the potential of formal, legal and financial limitations related to the findings of the conducted research. This is an important future research direction for the development and verification of theses on the possible development of the wind energy market in Poland, determining access to cheap electricity, especially needed in the era of the COVID-19 coronavirus pandemic.

It is worth pointing out that in the area of the countries accepted for the study, there were no studies devoted to analysing the prospects for the domestic wind energy industry from the perspective of the global energy transformation. Therefore, the research was based mainly on foreign scientific articles, studies, international reports, forecasts, prognostic estimates and statistical data. On their basis, the authors tried to grasp the main trends and issues related to the explored issues to consistently move from the global experience to the Polish and the Baltic countries' experience to answer the explored question. A critical analysis of the current situation was carried out and conclusions were drawn from an analysis of end consumer behaviour surveys and interviews conducted among representatives of companies active in the field of energy transformation were presented in order to work out a position regarding the intentions for the development of the wind energy market. All this was conducted to develop an up-to-date vision of plans and intentions (reliable forecast estimates).

The worldwide opening of environmental [72] protection and green energy [73–75] gives grounds to expect that the demand for green energy from wind will function on a large scale in Poland and the Baltic States. This is an important direction for developing investments in RES, giving a wide range of potential consumers the benefits of clean and cheap energy.

The reality of the COVID-19 coronavirus pandemic may affect the financial and organizational aspects of implementing activities and undertakings in the field of the implementation of climate policy assumptions of individual countries and the related transformation of energy sectors at the level of individual economies. The main problems in this regard arise from the lack or limited availability of production components, delays in the supply of materials and longer lead times for investments. Hence, the impact of COVID-19 on wind energy development in Poland and the Baltic States is mainly due to supply chain disruptions and delays in investment execution due to labour shortages. The above contributed to several months of delays in investment implementation. The current increase in prices of goods and services—also affecting the RES industry—is also partly a result of the weakening of the economy as a result of COVID-19.

The experience to date, related to implementing the projects discussed in this paper in the realities of the COVID-19 coronavirus pandemic, is optimistic. Contrary to the liquidity constraints, investments in the sphere of wind energy have reached a record level of EUR 26.3 billion in 2020, due to the implementation of offshore wind installations, which enables the continuation of efforts to acquire 7.1 GW of new connection capacities [76]. The above is promising and gives rise to predictions that the development of the wind energy market in Poland and the Baltic States will continue, enabling compliance with environmental requirements for the EU member states.

The findings of this study are a contribution to the problem of finding solutions for the development of the renewable energy market, with a particular emphasis on wind energy, which may realistically contribute to lower electricity purchase prices in Poland and the Baltic countries.

Despite the quantitative and spatial limitations of the study, the presented results give a significant view on the possible development potential of a cheap wind energy market in the studied area, providing a basis for further research and analysis in this area, with the use of more advanced instruments.

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References

1. IRENA. *Renewable Power Generation Costs in 2019*; IRENA: Abu Dhabi, United Arab Emirates, 2020.
2. Menegaki, A.; Tiwari, A. The Index of Sustainable Economic Welfare in the Energy-Growth Nexus for American Countries. *Ecol. Indic.* **2017**, *72*, 494–509. [CrossRef]
3. Ochoa, G.V.; Alvarez, J.N.; Acevedo, C. Research Evolution on Renewable Energies Resources from 2007 to 2017: A Comparative Study on Solar, Geothermal, Wind and Biomass Energy. *Int. J. Energy Econ. Policy* **2019**, *9*, 242–253. [CrossRef]
4. Magor, R. Renewable energy sources in the Lithuanian economy. *Energy Policy J.* **2017**, *20*, 140.
5. Zhou, E.; Cole, W.; Frew, B. Valuing variable renewable energy for peak demand requirements. *Energy* **2018**, *165*, 499–511. [CrossRef]
6. Yang, L.; Wang, X.-C.; Dai, M.; Chen, B.; Qiao, Y.; Deng, H.; Zhang, D.; Zhang, Y.; Almeida, C.; Chiu, A.; et al. Shifting from Fossil-Based Economy to Bio-Based Economy: Status Quo, Challenges, and Prospects. *Energy* **2021**, *228*, 120533. [CrossRef]
7. Donadio, L.; Fang, J.; Porté-Agel, F. Numerical Weather Prediction and Artificial Neural Network Coupling for Wind Energy Forecast. *Energies* **2021**, *14*, 338. [CrossRef]
8. Washburn, C.; Romero, M.P. Measures to promote renewable energies for electricity generation in Latin American countries. *Energy Policy* **2019**, *128*, 212–222. [CrossRef]
9. Eren, B.M.; Taspinar, N.; Gokmenoglu, K.K. The impact of financial development and economic growth on renewable energy consumption: Empirical analysis of India. *Sci. Total Environ.* **2019**, *663*, 189–197. [CrossRef]
10. Golarz, M. *Poland's Energy Security on the Example of Natural Gas, Crude Oil and Electricity Supplies, "Security Theory and Practice"*; Krakowska Akademia im. Andrzeja Frycza Modrzewskiego, Oficyna Wydawnicza AFM: Kraków, Poland, 2016; p. 11.
11. Ruszel, M.; Podmiotko, S. (Eds.) *Energy Security of Poland and Europe—Conditions—Challenges—Innovations, Institute of Energy Policy by Name I*; Łukasiewicz: Rzeszów, Poland, 2019; pp. 5–8.
12. Chomać-Pierzecka, E.; Kokiel, A.; Rogozińska-Mitrut, J.; Sobczak, A.; Soboń, D.; Stasiak, J. Analysis and Evaluation of the Photovoltaic Market in Poland and the Baltic States. *Energies* **2022**, *15*, 669. [CrossRef]
13. York, R.; Bell, S.E. Energy transitions or additions?: Why a transition from fossil fuels requires more than the growth of renewable energy. *Energy Res. Soc. Sci.* **2019**, *51*, 40–43. [CrossRef]

14. Miller, L.; Carriveau, R. A review of energy storage financing-learning from and partnering with the renewable energy industry. *J. Energy Storage* **2018**, *19*, 311–319. [CrossRef]
15. Benedek, J.; Sebestyén, T.; Bartók, B. Evaluation of renewable energy sources in peripheral areas and renewable energy-based rural development. *Renew. Sustain. Energy Rev.* **2018**, *90*, 516–535. [CrossRef]
16. Ajayi, O.O.; Ohijeagbon, O.D.; Nwadialo, C.E.; Olasope, O. New model to estimate daily global solar radiation over Nigeria. *Sustain. Energy Technol. Assess.* **2014**, *5*, 28–36. [CrossRef]
17. Ben Jebli, M.; Ben Youssef, S. The Environmental Kuznets Curve, Economic Growth, Renewable and Non-Renewable Energy, and Trade in Tunisia. Renew. *Sustain. Energy Rev.* **2015**, *47*, 173–185. [CrossRef]
18. Ajayi, O.O.; Fagbenle, R.O.; Katende, J.; Ndambuki, J.M.; Omole, D.O.; Badejo, A.A. Wind Energy Study and Energy Cost of Wind Electricity Generation in Nigeria: Past and Recent Results and a Case Study for South West Nigeria. *Energies* **2014**, *7*, 8508–8534. [CrossRef]
19. Novas, N.; Alcayde, A.; Robalo, I.; Manzano-Agugliaro, F.; Montoya, F.G. Energies and Its Worldwide Research. *Energies* **2020**, *13*, 6700. [CrossRef]
20. Menegaki, A.N.; Tugcu, C.T. Energy Consumption and Sustainable Economic Welfare in G7 Countries; A Comparison with the Conventional Nexus. *Renew. Sustain. Energy Rev.* **2017**, *69*, 892–901. [CrossRef]
21. Nguyen, N.T.; Matsuhashi, R.; Vo, T.T.B.C. A design on sustainable hybrid energy systems by multi-objective optimization for aquaculture industry. *Renew. Energy* **2021**, *163*, 1878–1894. [CrossRef]
22. Slusarczyk, B.; Zegle'n, P.; Kluczek, A.; Nizioł, A.; Górka, M. The Impact of Renewable Energy Sources on the Economic Growth of Poland and Sweden Considering COVID-19 Times. *Energies* **2022**, *15*, 332. [CrossRef]
23. Quitzow, R.; Bersalli, G.; Eicke, L.; Jahn, J.; Lilliestam, J.; Lira, F.; Marian, A.; Süsser, D.; Thapar, S.; Weko, S.; et al. The COVID-19 Crisis Deepens the Gulf between Leaders and Laggards in the Global Energy Transition. *Energy Res. Soc. Sci.* **2021**, *74*, 101981. [CrossRef]
24. Salim, R.A.; Rafiq, S. Why Do Some Emerging Economies Proactively Accelerate the Adoption of Renewable Energy? *Energy Econ.* **2012**, *34*, 1051–1057. [CrossRef]
25. *Polityka Energetyczna Polski do 2030 Roku*; Ministerstwo Gospodarki: Warszawa, Poland, 2009.
26. Sampaio, P.G.V.; González, M.O.A. Photovoltaic solar energy: Conceptual framework. *Renew. Sustain. Energy Rev.* **2017**, *74*, 590–601. [CrossRef]
27. Zhu, Y.; Cheng, M.; Hua, W.; Wang, W. A Novel Maximum Power Point Tracking Control for Permanent Magnet Direct Drive Wind Energy Conversion Systems. *Energies* **2012**, *5*, 1398–1412. [CrossRef]
28. Available online: https://pl.wikipedia.org/wiki/Energia_wiatru (accessed on 7 February 2022).
29. Onshore Wind Energy in Poland, Report 2021. Available online: https://psew.pl/wp-content/uploads/2021/05/Raport_Ladowa-energetyka-wiatrowa-w-Polsce_2021-05-11.pdf (accessed on 7 February 2022).
30. Sustainable Development Report 2019. Transformations to Achieve the Sustainable Development Goals. Available online: https://s3.amazonaws.com/sustainabledevelopment.report/2019/2019_sustainable_development_report.pdf (accessed on 3 February 2022).
31. Ghaffarzadeh, H.; Mehrizi-Sani, A. Review of Control Techniques for Wind Energy Systems. *Energies* **2020**, *13*, 6666. [CrossRef]
32. Gasset, N.; Landry, M.; Gagnon, Y. A Comparison of Wind Flow Models for Wind Resource Assessment in Wind Energy Applications. *Energies* **2012**, *5*, 4288–4322. [CrossRef]
33. Carrillo, C.; Feijoo, A.E.; Cidras, J.; Gonzalez, J.A.G.J. Power fluctuations in an isolated wind plant. *IEEE Trans. Energy Convers.* **2004**, *19*, 217–221. [CrossRef]
34. Carta, J.A.; Ramírez, P.; Velázquez, S. A review of wind speed probability distributions used in wind energy analysis: Case studies in the Canary Islands. *Renew. Sustain. Energy Rev.* **2009**, *13*, 933–955. [CrossRef]
35. Xu, Q.; He, D.; Zhang, N.; Kang, C.; Xia, Q.; Bai, J.; Huang, J. A short-term wind power forecasting approach with adjustment of numerical weather prediction input by data mining. *IEEE Trans. Sustain. Energy* **2015**, *6*, 1283–1291. [CrossRef]
36. Zhao, P.; Wang, J.; Xia, J.; Dai, Y.; Sheng, Y.; Yue, J. Performance evaluation and accuracy enhancement of a day-ahead wind power forecasting system in China. *Renew. Energy* **2012**, *43*, 234–241. [CrossRef]
37. Ramirez-Rosado, I.; Fernandez-Jimenez, L.; Monteiro, C.; Sousa, J.M.; Bessa, R. Comparison of two new short-term wind-power forecasting systems. *Renew. Energy* **2009**, *34*, 1848–1854. [CrossRef]
38. Mana, M.; Burlando, M.; Meißner, C. Evaluation of two ANN approaches for the wind power forecast in a mountainous site. *Int. J. Renew. Energy Res.* **2017**, *7*, 1629–1638.
39. Men, Z.; Yee, E.; Lien, F.S.; Wen, D.; Chen, Y. Short-term wind speed and power forecasting using an ensemble of mixture density neural networks. *Renew. Energy* **2016**, *87*, 203–211. [CrossRef]
40. Carrillo, C.; Cidrás, J.; Díaz-Dorado, E.; Obando-Montaño, A.F. An Approach to Determine the Weibull Parameters for Wind Energy Analysis: The Case of Galicia (Spain). *Energies* **2014**, *7*, 2676–2700. [CrossRef]
41. Larsson, A. Flicker emission of wind turbines during continuous operation. *IEEE Trans. Energy Convers.* **2002**, *17*, 114–118. [CrossRef]
42. Abdullah, M.A.; Yatim, A.H.M.; Tan, C.W.; Saidur, R. A review of maximum power point tracking algorithms for wind energy systems. *Renew. Sustain. Energy Rev.* **2012**, *16*, 3220–3227. [CrossRef]

43. Tan, K.; Islam, S. Optimal control strategies in energy conversion of PMSG wind turbine system without mechanical sensors. *IEEE Trans. Energy Convers.* **2004**, *19*, 392–399. [CrossRef]
44. Agarwal, V.; Aggarwal, R.K.; Patidar, P.; Patki, C. A novel scheme for rapid tracking of maximum power point in wind energy generation systems. *IEEE Trans. Energy Convers.* **2010**, *25*, 228–236. [CrossRef]
45. Vita, G.; Šarki´c-Glumac, A.; Hemida, H.; Salvadori, S.; Baniotopoulos, C. On the Wind Energy Resource above High-Rise Buildings. *Energies* **2020**, *13*, 3641. [CrossRef]
46. Fuglsang, P.; Bak, C.; Schepers, J.G.; Bulder, B.H.; Cockerill, T.; Claiden, P.; Olesen, A.; van Rossen, R. Site-specific Design Optimization of Wind Turbines. *Wind Energy* **2002**, *5*, 261–279. [CrossRef]
47. Hansen, K.S.; Barthelmie, R.J.; Jensen, L.E.; Sommer, A. The impact of turbulence intensity and atmospheric stability on power deficits due to wind turbine wakes at Horns Rev wind farm. *Wind Energy* **2012**, *15*, 183–196. [CrossRef]
48. Pagnini, L.C.; Burlando, M.; Repetto, M.P. Experimental power curve of small-size wind turbines in turbulent urban environment. *Appl. Energy* **2015**, *154*, 112–121. [CrossRef]
49. Kumar, Y.; Ringenberg, J.; Depuru, S.S.; Devabhaktuni, V.K.; Lee, J.W.; Nikolaidis, E.; Andersen, B.; Afjeh, A. Wind Energy: Trends and Enabling Technologies. *Renew. Sustain. Energy Rev.* **2016**, *53*, 209–224. [CrossRef]
50. Esteban, M.D.; Diez, J.J.; López, J.S.; Negro, V. Why Offshore Wind Energy? *Renew. Energy* **2011**, *36*, 444–450. [CrossRef]
51. Available online: https://ec.europa.eu/eurostat (accessed on 2 January 2022).
52. Evolution of Household Electricity and Gas Prices in the EU. Available online: https://ec.europa.eu/eurostat/documents/4187653/11581527/Evolution+of+household+electricity+and+gas+prices+in+the+EU.png/8e8a38f6-e791-ee36-c14c-844b91fad606?t=1634632173305 (accessed on 29 November 2021).
53. Electrisity Prices in Poland Are among the Highest in the World in Relations to Salaries. Available online: https://wysokienapiecie.pl/43543-ceny-pradu-w-polsce-wsrod-najwyzszych-na-swiecie-w-stosunku-pensji/ (accessed on 7 February 2022).
54. Available online: https://www.enea.pl/dlafirm/obsluga_klienta_i_kontakt/pliki_do_pobrania/2020/taryfa_abcr_2020.pdf (accessed on 7 February 2022).
55. Available online: https://www.enea.pl/dlafirm/oferty_dla_firmy/pliki_do_pobrania/09.06.2021/taryfa_abcr_010721.pdf (accessed on 7 February 2022).
56. Lai, C.S.; McCulloch, M.D. Levelized cost of electricity for solar photovoltaic and electrical energy storage. *Appl. Energy* **2017**, *190*, 191–203. [CrossRef]
57. Available online: https://www.enea.pl/dlafirm/obsluga_klienta_i_kontakt/2021/taryfa_abcr_01012022_www.pdf (accessed on 7 February 2022).
58. Electricity Tariff for Customers from Tariff Groups A, B, C, R, Enea S.A. ABCR/02/2022/39672 of 27.01.2022. Available online: https://www.enea.pl (accessed on 7 February 2022).
59. Available online: https://www.ure.gov.pl/pl/urzad/informacje-ogolne/edukacja-i-komunikacja/publikacje/seria-wydawnicza-bibli/jaki-model-rynku-energ/1183,1-Model-rynku-energii-elektrycznej.html (accessed on 7 February 2022).
60. Ministry of Climate and Environment. *Energy Policy of Poland until 2040*; Ministry of Climate and Environment: Warsaw, Poland, 2021.
61. Varela-Vázquez, P.; del Carmen Sánchez-Carreira, M. Estimation of the Potential Effects of Offshore Wind on the Spanish Economy. *Renew. Energy* **2017**, *111*, 815–824. [CrossRef]
62. Kaldellis, J.K.; Kapsali, M. Shifting towards Offshore Wind Energy—Recent Activity and Future Development. *Energy Policy* **2013**, *53*, 136–148. [CrossRef]
63. Bilgili, M.; Yasar, A.; Simsek, E. Offshore Wind Power Development in Europe and Its Comparison with Onshore Counterpart. *Renew. Sustain. Energy Rev.* **2011**, *15*, 905–915. [CrossRef]
64. Farkas, A.; Degiuli, N.; Marti´c, I. Assessment of Offshore Wave Energy Potential in the Croatian Part of the Adriatic Sea and Comparison with Wind Energy Potential. *Energies* **2019**, *12*, 2357. [CrossRef]
65. GWEC. *Global Wind Report 2019*; Global Wind Energy Council: Brussels, Belgium, 2020.
66. IEA. *Offshore Wind Outlook 2019: World Energy Outlook Special Report*; International Energy Agency: Paris, France, 2019.
67. Pronińska, K.; Księzopolski, K. Baltic Offshore Wind Energy Development—Poland's Public Policy Tools Analysis and the Geostrategic Implications. *Energies* **2021**, *14*, 4883. [CrossRef]
68. COWI; Directorate-General for Energy (European Commission); Ea Energy Analyses; THEMA Consulting Group. *Study on Baltic Offshore Wind Energy Cooperation under BEMIP: Final Report*; Publications Office of the European Union: Luxembourg, 2019; ISBN 978-92-76-09690-0.
69. European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. An EU Strategy to Harness the Potential of Offshore Renewable Energy for a Climate Neutral Future*; European Commission: Brussels, Belgium, 2020.
70. Bogusz, M.; Matysik-Pejas, R.; Krasnodębski, A.; Dziekański, P. The Concept of Zero Waste in the Context of Supporting Environmental Protection by Consumers. *Energies* **2021**, *14*, 5964. [CrossRef]
71. Andrei, J.V.; Mieila, M.; Panait, M. The impact and determinants of the energy paradigm on economic growth in European Union. *PLoS ONE* **2017**, *12*, e0173282. [CrossRef] [PubMed]
72. Li, Z.; Wang, J.; Che, S. Synergistic Effect of Carbon Trading Scheme on Carbon Dioxide and Atmospheric Pollutants. *Sustainability* **2021**, *13*, 5403. [CrossRef]

73. Omri, A.; Daly, S.; Nguyen, D.K. A Robust Analysis of the Relationship between Renewable Energy Consumption and Its Main Drivers. *Appl. Econ.* **2015**, *47*, 2913–2923. [CrossRef]
74. Pestana, D.G.; Rodrigues, S.; Morgado-Dias, F. Environmental and economic analysis of solar systems in Madeira, Portugal. *Util. Policy* **2018**, *55*, 31–40. [CrossRef]
75. Peng, J.; Lu, L.; Yang, H. Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. *Renew. Sustain. Energy Rev.* **2013**, *19*, 255–274. [CrossRef]
76. WindEurope: The Coronavirus Has Not Stopped Offshore Development in Europe. Available online: https://biznesalert.pl/rozwoj-morskich-farm-wiatrowych-2020-offshore-oze-energetyka/ (accessed on 10 February 2022).

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Article

The Impact of Renewable Energy Sources on the Economic Growth of Poland and Sweden Considering COVID-19 Times

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Abstract: A demonstration of the relationship between the share of renewables in gross marginal energy and selected countries' economic growth is the basis of this research. The paper seeks to investigate mutual correlations between renewable energy sources and economic growth for two EU economies and how it influences their fluctuations (increase and decrease). The comparative analysis of results was carried out for less-income Polish and high-income Swedish economies. This research used a regression model to answer the research questions examining the presence of correlations between renewable energy sources in gross marginal energy consumption and economic growth. This study analyzes data starting from 1991 to 2022. The results indicated a positive correlation (statistical significance) between Gross Domestic Product and Gross National Income variables for Sweden (84.6% and 83.7%, respectively) and Poland (79.9% and 79.2%, respectively), which influence the use of renewable energy sources. The findings also reveal that the higher economic growth caused by the use of renewables is observed for the leading countries but at the same time the risk of a greater recession is much more likely than in other countries. These findings would help government officials and policymakers to better understand the role of renewable energy in the economic growth of these countries. This study has contributed to the literature on renewable energy sources and statistical reports under the EU energy sector framework.

Keywords: economic growth; renewable energy sources (RES); Gross Domestic Product (GDP); Gross National Income (GNI); regression model; Poland; Sweden; COVID-19

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1. Introduction

The growing "green" paradigm to minimalize energy use and its effect on climate change highlights the necessity for shifting from a fossil-based economy to renewables-based economy or bio-based economy [1]. However, the transformation process might go well delivering regular statistical data collection if not for unexpected events such as COVID-19, which disturbs and causes uncertainty in the evaluation of a factor's impact on the economic growth of both developing and developed countries.

The main motivation for writing the paper is to analyze the impact of three key issues regarding renewable energy sources (RES) and its influence on two coefficients, Gross Domestic Product (GDP) and Gross National Income (GNI), of Poland and Sweden. Moreover, because of existing unpredictable phenomena that are called "Black Swans" in the economy, the issues were examined considering the COVID-19 (perceived as the "Black Swan") era. The paper aims to examine correlations between renewable and economic growth in Poland and Sweden, improving the quality of the debate about RES and their influence on GDP and GNI from a COVID-19 perspective. The authors stated that the higher the share of RES, the better the economic growth and higher the GDP and GNI indicators. This choice of countries was made due to the existence of significant differences between them, not only economically but also related to renewable energy sources; this being the reason why the research concerning Sweden and Poland (no other well-developed and developed countries) is a randomized trial conducted among well-developed and developed European countries. To back the choice up, it is worth underlining that, in Sweden, the share of renewable energy in the gross marginal energy consumption in 2020 was over 92%. In turn, over 82% of the energy production in Poland is the energy obtained from non-renewable sources [2]. Additionally, another reason for choosing these two countries is a similar situation regarding economic growth, as the GDP ratio in 2015–2019 was at the given level. We also selected a variety of methods and research, performed to analyze the relationship between these countries, but mainly to investigate the impact of economic growth on the creation of power plants powered by renewable energy sources.

Over the years, several studies have been undertaken to investigate the correlations between RES and economic growth formulated in GDP and GNI indicators. The interconnections were mostly found as positive relations [3–10], and supported by technological innovations [11].

Similar research was carried out in various countries in terms of economy and policy [12–18], but the problem of influencing RES on the less-income Polish and high-income Swedish economies has not yet been addressed in this considered area. Hence, the authors of the paper tried to formulate a research gap, which is the lack of a casual interconnection between the energy-based economic factors (energy-GDP and energy-GNI) impacting the economic growth of these countries. Then, the relations are compared to each other to reveal the economic welfare gap with emphasis on COVID-19. In this study, the two variables considered are interdependent, but the research was carried out under various configurations of the variables (as per the level of dependency). To extend the current research in the field of RES, the authors put the main research questions as follows: (1) Is there a relationship between the share of RES in gross marginal energy consumption and economic growth? (2) Do the identified variables interact with each other using a regression model? These research questions were determined in relation to the research gap defining the problem statement.

The goal of the study is to examine the impact of the energy-related variables (GDI and GNI) on the level of economic growth in Poland and Sweden. Through the regression model, this research is intended to demonstrate an impact of renewable energy sources on the economic development through countries' economic factor structures. The selection of countries was based on data availability in EUROSTAT, World Bank and Internet reports, to provide a balanced sample and specifically for the environmental and political conditions and their successful establishment in the national markets. In addition, the selected countries to be analyzed should also outline the importance of RES, which is distributed unequally across the European Union countries (Sweden and Poland). According to the ranking of the Responsible Development Index and the 2019 Sustainable Development Report [19,20], Sweden was rated very highly amongst the world's most developed economies. Poland occupies a stagnating position regarding affordable and clean energy, thus not meeting the Sustainable Development Goals from the 2030 Agenda [21].

This article presents a linkage between the significant energy-related factors influencing the economic growth of Poland and Sweden—two distinct countries in terms of economy, policy, tradition, culture, location, etc. The current state of the research conducted in different parts of the world and in various countries has been carefully reviewed [17,22–26]. In the light of the reviewed literature, the authors of this paper derived the inspiration and need to treat/consider the research from a COVID-19 perspective. The perspective seems to be very important because it influenced all the spheres of our lives and made a contribution to decrease the GDP and GNI in all the countries. The paper is an attempt to disseminate the effects on the structure of the energy sector across the last 20 years, also considering the

COVID-19 pandemic, with a particular emphasis on the use of renewable energy sources. To meet the goal set out in the literature review, a regression model was used.

The paper is structured as follows: Section 1 includes introduction, Section 2 outlines the literature review, which explains the relations between the components of energy-based economic growth under constraints such as COVID-19. Section 3 covers the conceptual framework that defines the impact of RES on the economic growth of Poland and Sweden. Section 4 presents the research outcomes, followed by the recommendations implied by these results and the energy policy implication for economic growth. Section 5 states the discussion and Section 6 covers conclusions.

2. COVID-19 and Renewable Energy Sources—Literature Review

The crisis changed consumer behavior, which resulted in a reduction in the level of fossil fuel consumption in favor of an increase in demand for renewable energy. Regarding the energy sector, the impact of the crisis and the associated policy responses are reinforcing the existing trends in renewable energy, with leaders continuing to use renewable energy, while countries heavily dependent on the fossil fuel industry spend government spending on supporting these sectors, which additionally slows down the clean energy transition [27]. Pandemic restrictions in many countries did not affect electricity production from renewable sources. Global renewable energy consumption in all sectors increased by 1.5%, while renewable electricity production increased by almost 3% in the first quarter of 2020 compared to the same period in 2019. It resulted from new wind and solar PV projects completed within the last year and the fact that renewable energy sources have low marginal operating costs. As a result, the share of RES in electricity demand has increased in many regions affected by the pandemic blockade, including parts of Europe and the USA [28]. With the COVID-19 pandemic starting in 2020, RES accounted for as much as 90% of the added energy in the energy sector. The most significant contribution to such a large increase was made by photovoltaics and hydro and wind energy. According to the International Energy Agency (IEA) report [29], if the current trends continue until 2025, renewable energy will become the most significant energy source. It will meet a third of the global energy demand. Moreover, most of the shares of companies related to the sector doubled in value compared to December 2019. However, the COVID-19 pandemic provides unique information on how different societies are coping with emergencies and how the higher share of RES compared to traditional fuels will affect grid infrastructure, energy markets, and related investments [30–32]. Indeed, the lessons learned from the crisis will shape new policies and determine the long-term consequences for a more sustainable future. Achievements in industrial production have contributed to the increased use of fossil fuels on a large scale, making the energy sector a vital sector of most economies in the world. A disturbing phenomenon is the rapid depletion of oil, gas, and coal resources, which has significantly contributed to by the increase in the world's population, which, according to the United Nations forecasts, will reach the level of 10.9 billion by 2100. Moreover, the extraction of these raw materials becomes more complex and requires advanced technological solutions, which translates into an increase in costs and prices. Thanks to the growing awareness of the dangers of a fossil fuel-based energy, humanity has once again turned to solutions that use renewable energy. Extensive analysis of the literature concerning correlations between renewable energy sources and the economic growth of various countries is presented in this paper. Many countries (including Sweden, Finland, and Denmark [33], Bulgaria [34], Croatia [35], Estonia [36], the Czech Republic [37], Greece [18], and others) are changing their energy policy [2] because it has occurred to them that the renewables may (among others) constitute a way to strike a balance between economic growth and the quality of the environment. It is confirmed, among others, by EUROSTAT data, according to which the share of renewable energy sources in the energy policy of most countries from 28 countries has increased, and 12 European Union members have already achieved the target of a 20% share of energy from renewable sources in the gross final energy consumption in the community in 2020. With the growing level of RES use by European countries, an in-depth analysis of the impact of various factors on this phenomenon is present in numerous publications [38–40]. In the group of factors there are listed increases in oil prices caused by geopolitical threats, the necessity of climate changes mitigations, increase in energy security, GDP, and elimination of carbon-intensive fuels. Peculiarly high carbon dioxide (CO2) emissivity as a result of using traditional energy sources as well as economic growth measured in GDP are the main reasons why separate countries change their energy policy and use RES [41–43]. Moreover, the empirical findings show that an ever-greater use of renewable energies may sustain the economic growth process and have a positive significant impact on GDP improvement and economic development, not only in European and well-developed countries, but [44–46] also in SAARC countries (South Asian Association for Regional Cooperation) [47] and Latin American countries [48,49]. This novel empirical research resulted in creating a new energy policy to reach goals in the area of sustainable economic growth in many countries, especially in EU countries. Therefore, RES consumption plays a determining role in improving economic growth in numerous European and non-European countries. Scientists confirm that the exploitation of renewable energy sources brings many benefits, such as reducing environmental pollution, reducing the consumption of fossil fuels, and reducing the costs of energy production and supply [50–52]. In view of the foregoing, Europe is gradually moving away from non-renewable energy sources in favor of "green energy", the share of which in Europe's energy sector is increasing even in the face of the crisis caused by the COVID-19 pandemic. Mandatory quarantine contributed to a significant decrease in environmental pollution by reducing the consumption of fossil fuels in favor of increasing the demand for renewable energy sources [53–56]. The research undertaken by scientists allowed to assess the impact of the coronavirus pandemic on the energy sector, also in terms of investment and use of renewable energy [46–48]. Such an acceleration of activities can offset the harmful effects of the COVID-19 global pandemic. Despite the crisis caused by the COVID-19 pandemic in 2020, which affected many industries, including the energy sector, the increase in renewable energy was observed, especially wind and solar energy [27]. Global power of RES (that constitute almost 30% in all the energy mixture) increased to about 260 GW [57]. The International Energy Agency (IEA) [17] also reports on the excellent condition of RES. Despite the disturbances in the energy sector due to the pandemic, in the first quarter of 2020 (i.e., in the conditions of the ongoing pandemic), only renewable energy sources recorded a 1.5% increase in demand with a parallel decrease in demand for coal, oil, and natural gas. Many authors [57–59] wrote about the essential maintenance of the growth in demand for renewable energy in the conditions of lockdown and pandemic constraints. The most significant decrease in demand by approx. 15% concerned electricity, especially in countries where strict health restrictions were introduced. Forecasts indicate that the demand for fossil fuel sources will continue to decline. Only the demand for renewable energy sources will increase, which means a favorable prognosis for this energy field [19]. The coronavirus pandemic and the global crisis it causes, combined with climate threats, made it necessary to adjust the energy policy to include renewable sources of electricity. The introduction of renewable energy sources into the energy sector by many countries has become a priority in their policy of building energy security. When comparing Poland and Sweden with respect to energy policy, one has to emphasize that Sweden is the undisputed leader in the energy transformation rankings [60]. Unfortunately, Poland is placed 69th (between Bolivia and Indonesia). Sweden was using RES in 33% of its total energy production in 1990, and the aim of using "green energy" in 50% (planned for 2020) was achieved in 2012. Sweden aims to support domestic energy use by total use of RES, and they want to achieve the goal in 2040. The importance and the growing share of renewable energy sources is also one of the sustainable targets for Poland within its energy policy [61]. As an EU target, the energy policy assumes a 21–23% increase in the share of renewable energy sources in the energy mix by 2030 [20]. Additionally, the report addresses the carbon share in energy production (it is going to be decreased up to 60% whereas today it is 80%), and the RES share in the oil and energy sector will equal 28.5% in 2040 [62]. The relationships between the components of energy-based economic growth under constraints such as COVID-19 is outlined in Figure 1.

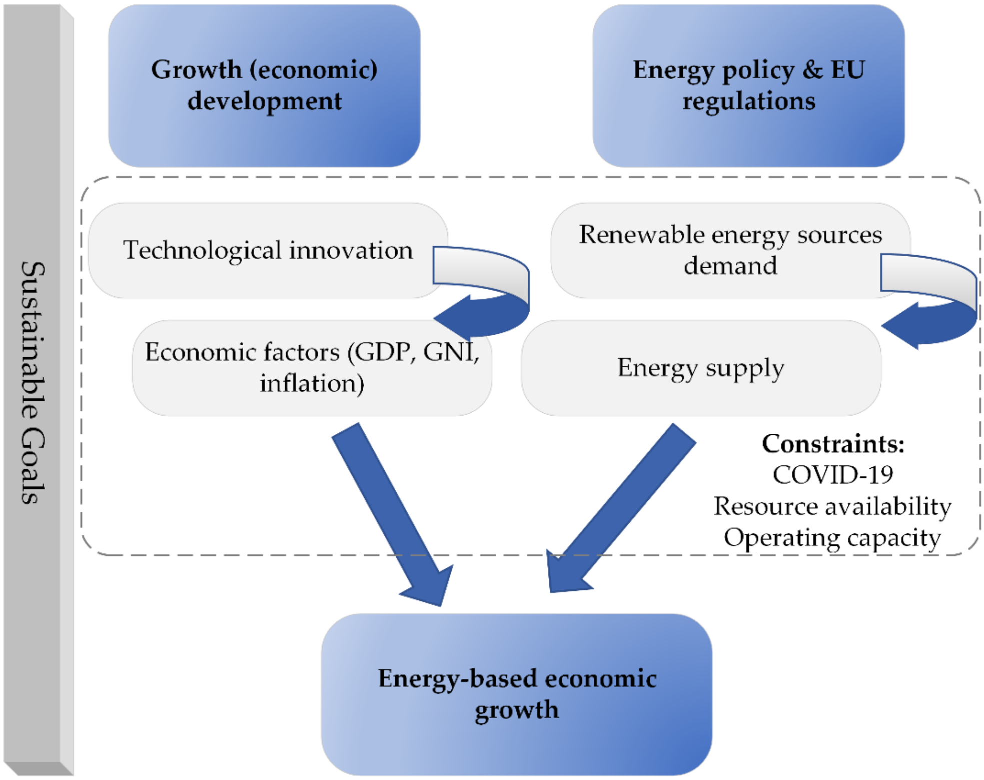

Figure 1. Energy-based economic growth. Source: Own elaboration.

The foregoing literature review concerning correlations between the renewable energy sources and economic growth of various countries regarding the COVID-19 pandemic constitutes a background for the research analyzing two different countries with various energy resource sharing coefficients in their final use of gross energy (Poland and Sweden). These countries were selected considering a highly developed economy against a less-developed one to identify the gross energy consumption disparities between them. Usually, these analyses are being carried out to compare extremely developed countries (with less-income vs. high-income economy) or for developing countries [54]. Data analyses through the use of a regression model will allow solving the problem of an "asymmetrical distribution" of renewable energy sources between both countries.

3. Materials and Methods

The study uses the data from EUROSTAT and the World Bank selected by the researchers. The idea is to show to which extent the impact of RES occurs in developed countries, which are characterized mostly by Gross Domestic Product and Gross National Income.

In this paper, the authors used a conceptual framework for defining the impact of RES on the economic growth of Poland and Sweden, as presented in Figure 2. It consists of the following stages:

1. Problem statement based on the literature review and observations of the economic situation in Europe.
2. Selection of countries using a randomized trial performed by the authors of the paper.
3. Analysis of the energy-related economic variables based on available reports, scientific papers, and statistical data from EUROSTAT and the World Bank, which was a basis for the calculation of a correlation coefficient. For the analysis, GDP, GNI, and RES were taken to calculate the correlation coefficients considering the impact of RES on the

economic growth for the variables for Poland and Sweden. Fundamental indicators, such as standard deviation and coefficient of determination, were also analyzed.

4. Building a regression model, we find the relations between the economic variables, with the use of the time series method. Moreover, to analyze the economic variables in a proper way, the authors have divided the variables into endogenous (RES) and exogenous (GDP, GNI) ones. STASTISTICA 13.1 software was used to obtain the research results. The steps required to carry out and validate the variables are as follows:
    4.1. Analysis of various regression models in the literature on the considered topic [16,63,64];
    4.2. Linear regression model was applied to find correlations between the analyzed economic variables;
    4.3. The regression model used in the study is a kind of panel data fixed-effects regression model denoting the GDP, GNI, and RES variables;
    4.4. Responsiveness to changes of the variables' creation was obtained in the final step of analysis.
5. Comparative analysis of the results in terms of the three selected economic variables' correlations for both countries.
6. Results discussion.

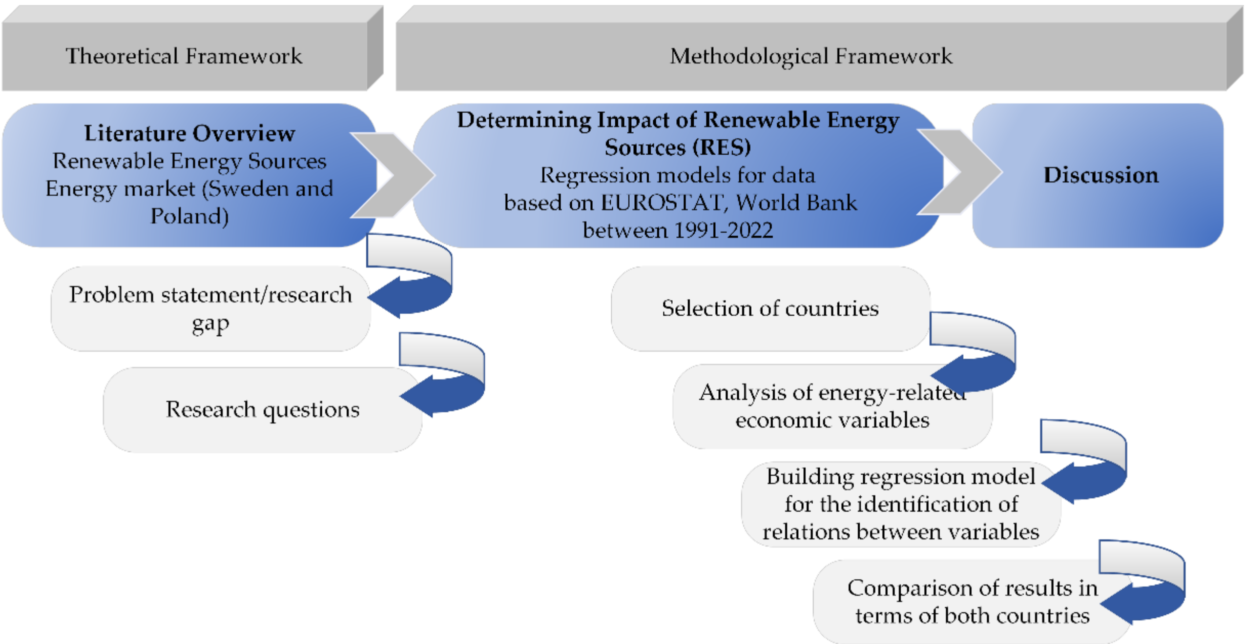

Figure 2. The proposed conceptual framework for determining the impact of RES on the economic growth.

Having this schematic structure of the study, a correlation coefficient between the renewables and economic growth for Sweden and Poland can be investigated. The research uses time interval series data starting from 1991 to 2022.

Having the linear regression model built, the authors could identify the relations between the variables to carry out and validate them. The authors of the paper referred to other works that used similar regression models with a fixed-effects approach in the context of renewables use and its impact on economic growth [16,63,64].

4. Results

The researchers focused their analysis on the relations between three variables (GDP, GNI, and RES), which means that it was investigated whether the changes in the shaping of the X variables (GDP and GNI) influenced the changes in the Y variable (RES).

Table 1 shows the results of the correlation coefficients between the variables GDP, GNI, and RES and gross final energy consumption in Poland and Sweden from 1991 to 2020, as well as the prognosis made for 2021 and 2022.

Table 1. Coefficients of the Gross Domestic Product (GDP), Gross National Income (GNI), and renewable energy resources (RES) share in the final use of gross energy.

% Share of Renewable Energy in Gross Final Energy Consumption			Gross Domestic Product (GDP)			Gross National Income (GNI)		
Years	**Poland**	**Sweden**	**Years**	**Poland (Billion Dollars)**	**Sweden (Billion Dollars)**	**Years**	**Poland (Billion Dollars)**	**Sweden (Billion Dollars)**
1991	2.06	32.46	1991	85.50	271.98	1991	82.65	265.72
1992	2.3	33.23	1992	94.34	281.99	1992	90.34	272.06
1993	6.13	34.39	1993	96.05	211.21	1993	92.55	202.59
1994	6.19	31.35	1994	110.80	227.27	1994	109.81	221.47
1995	6.33	33.91	1995	142.14	265.39	1995	140.14	259.83
1996	5.86	31.36	1996	159.94	289.76	1996	158.87	283.99
1997	5.98	35.62	1997	159.12	266.38	1997	157.99	261.16
1998	6.54	35.66	1998	174.39	268.92	1998	173.20	265.02
1999	6.41	34.79	1999	169.72	272.29	1999	168.71	271.86
2000	6.93	40.01	2000	171.89	261.34	2000	171.16	261.50
2001	7.21	37.66	2001	190.52	241.02	2001	189.91	241.20
2002	7.49	36.15	2002	198.68	265.34	2002	198.01	266.10
2003	7.29	34.91	2003	217.51	332.27	2003	215.41	337.90
2004	6.914	38.677	2004	255.10	382.62	2004	246.98	384.80
2005	6.9	40.72	2005	306.12	389.75	2005	300.78	395.09
2006	6.888	42.447	2006	344.75	420,22	2006	337.48	431.20
2007	6.93	43.929	2007	429.06	487.97	2007	414.66	502.69
2008	7.713	44.666	2008	533.82	515.41	2008	524.47	533.27
2009	8.661	47.88	2009	439.80	435.11	2009	426.59	445.35
2010	9.253	46.958	2010	479.32	495.33	2010	462.20	508.80
2011	10.295	48.245	2011	528.83	572.74	2011	509.76	584.48
2012	10.897	50.23	2012	500.36	550.93	2012	481.70	563.58
2013	11.68	50.8	2013	524.23	584.64	2013	506.69	597.82
2014	11.495	51.874	2014	545.39	580.25	2014	525.24	592.53
2015	11.743	53.009	2015	477.58	503.65	2015	460.25	508.19
2016	11.267	53.371	2016	472.03	515.74	2016	453.44	519.29
2017	10.964	54.201	2017	526.22	540.54	2017	504.58	548.71
2018	11.284	54.645	2018	585.66	556.09	2018	560.91	564.72
2019	12.164	56.391	2019	570.78	551.03	2019	546.84	559.08
2020	11.69	59.48	2020	570.04	566.25	2020	531.51	570.64
2021	12.34	61.05	2021	587.16	576.51	2021	548.44	584.42
2022	12.61	61.66	2022	604.27	586.76	2022	565.37	598.20

Source: Own elaboration on the basis of EUROSTAT and World Bank data.

An increasing tendency has been observed in both countries but it is worth it to underline that the share is much higher in Sweden than in Poland. Moreover, the increase in Poland is not regular and some decreases are noticed (within the period of 2015 to 2020). The correlation between the use of RES, GDP, and GNI show the well-developed country is more advanced in using RES. The forecasts are also optimistic because the use of RES is increasing but the pace of the increase is higher in Sweden again.

Figure 3 presents the correlation between GDP, GNI, and RES for Poland and Sweden within the period of 1991–2022 (with extrapolation).

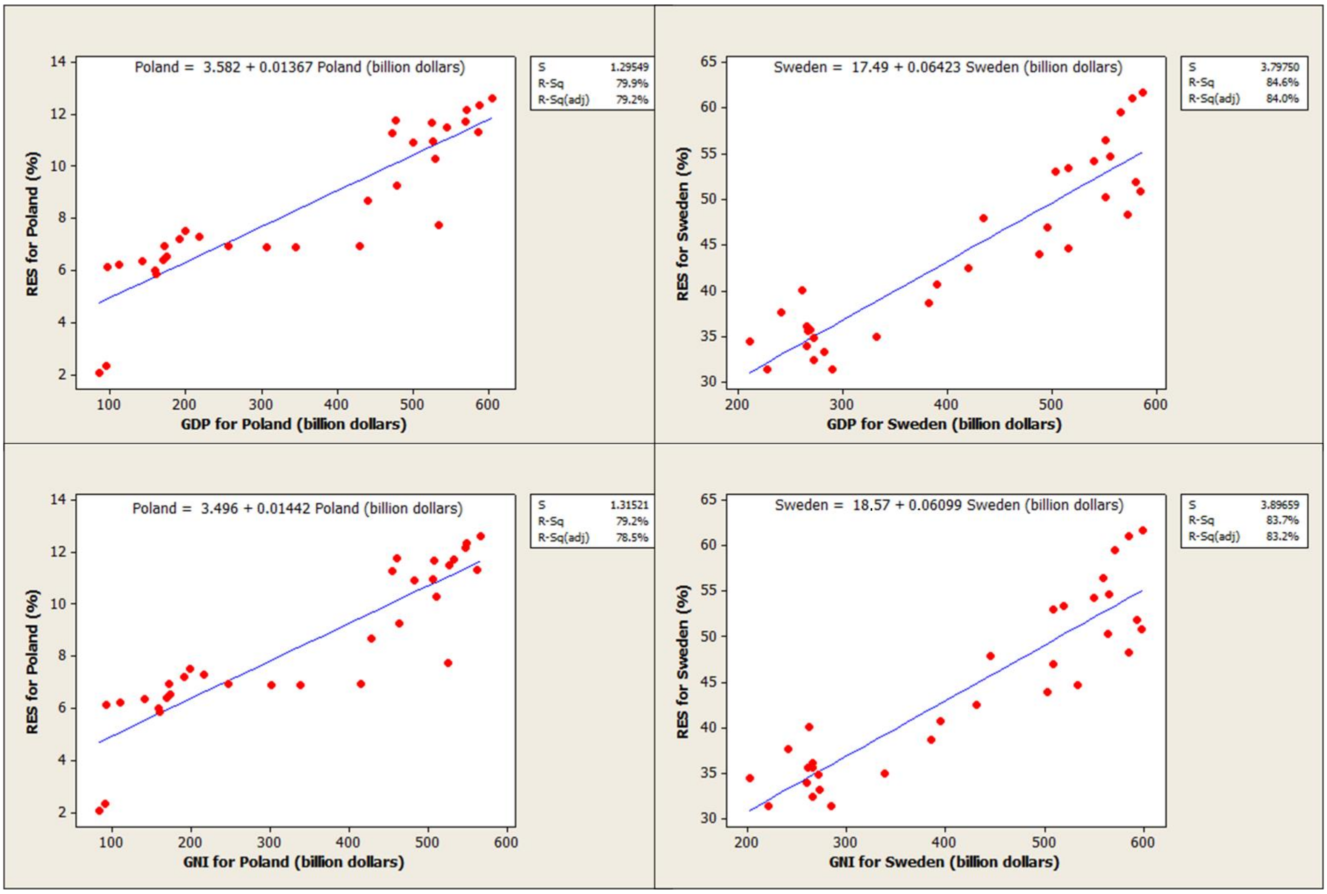

Figure 3. Correlations between GDP, GNI (in billion USD), and RES for Poland and Sweden.

Correlations between GDP, GNI, and RES for both Poland and Sweden are very high. Relations between RES and GDP for Poland and Sweden (79.9% and 84.6%, respectively) indicate a good fit between the analyzed variables. The standard deviation for Poland and Sweden (S = 1.29549 and S = 3.79750, respectively) shows that GDP values are not dispersed widely around its average. Correlations between RES and GNI for Poland and Sweden (79.2% and 83.7% respectively) also point at an accurate fit between the variables. The GNI values for Poland and Sweden are not so dispersed around its average (S = 1.31521 and S = 3.89659, respectively), as is shown in Figure 3.

Figure 4 depicts high values of the coefficient of determination (R-Sq = 84.3%), which means that the model provides a good fit and the authors of the paper can have confidence in its ability to predict the future share of RES for both analyzed countries. It determines the independent variable (RES), which means that the data fit well the regression model. The standard deviation (S) equals 1.14516, which means that the RES values are not dispersed widely around its average. Nevertheless, if R-Sq is high, there is still ambiguity in how large the percentage needs to be in order to be considered a good fit. Based on the statistics generated, linear regression is still an optimal forecasting method. Viewed in terms of prediction, the estimated trend is increasing because a part of the extrapolated series give the clearest indication of the future movements in the series. Thereupon, the forecast presented in Figure 4 estimates the best fit regression line for the given data.

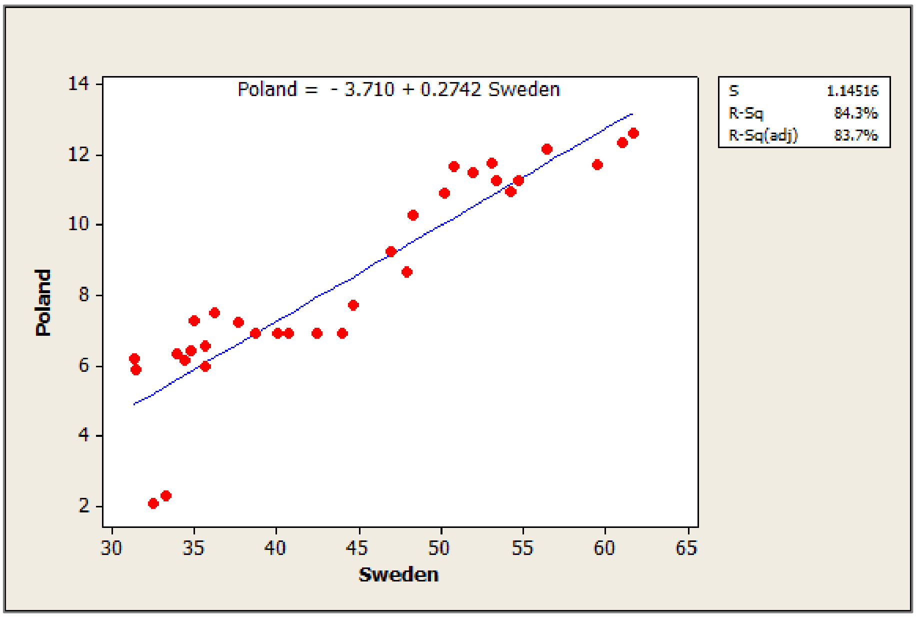

Figure 4. Poland's and Sweden's coefficient of RES.

4.1. Regression Model Based on Variable Y (Renewable) and Variable X (GDP) for Poland

The dependent Y variable (RES) is the share of renewable energy sources in gross energy consumption. In turn, the variables GDP and GNI are the explanatory X variables. The variables are opposite—GDP and GNI are dependent variables, whereas RES is an explanatory variable. The results of modeling the GDP influencing the share of RES in gross marginal energy consumption in Poland within 1991–2022 are presented in Table 2.

Table 2. Results of modeling the share of renewable energy sources in gross marginal energy consumption in Poland in 1991–2022 using a linear econometric model of one variable.

N = 32	**R = 0.89383973, R^2 = 0.79894947, Corr. R^2 = 0.79224778 F(1.30) = 119.22, p < 0.00000, Std Error of Estim. 1.2892**			
	Coefficients	**Standard Error**	**t-Stat**	***p* Value**
Absolute term	3.589947	0.494204	7.26410	0.00000004
GDP (X_1)	0.013618	0.001247	10.91862	0.00000000

The model of the share of renewable energy sources in gross marginal energy consumption in Poland (GDP) is outlined in Equation (1):

$$\hat{Y}_t = 3.58995 + 0.013618\ X_1 \quad (1)$$

The estimated model shows that if the X_1 variable denoting the amount of GDP expressed in USD billion increases by one whole unit (USD 1 billion), the share of renewable energy sources in gross marginal energy consumption will also increase by 13.618%. The intercept is the data that determines the magnitude of the value of Y for the period preceding the analyzed phenomenon. It is a constant and independent value, and its positive value, in this case, means that with each successive period, the variable Y will increase.

The estimated econometric model is relatively well-adjusted to the empirical data and reflects the changes of this phenomenon over time in 79.89%. It is evidenced by the value of the R^2 coefficient = 0.7989. The actual values of the share of renewable energy sources in the gross marginal energy consumption in subsequent years deviate from the estimated model by 1.2892% on average. On the other hand, the residual deviation, speaking about the average deviation of the theoretical values from the arithmetic mean of empirical values, is $S_e = 1.299\%$.

The last phenomenon presented is the importance of the structural parameters. The hypotheses can be presented as follows: the hypothesis H_0 applies to the situation where it = 0, and the parameter is statistically insignificant. On the other hand, there is the H_1 hypothesis, where it $\neq 0$ and the parameter is statistically significant. Satisfying the *p*-value inequality implies the rejection of the H_0 hypothesis in favor of the H_1 alternative. In the tested example, $\alpha = 0.05$, and the value *p*, as shown in Table 2, is a minimal value, and its first number is at the 8th decimal place. This relationship shows that the H_0 hypothesis was rejected, favoring the H_1 alternative, which means that the structural parameter is statistically significant. The variable X_1 has a significant impact on the dependent variable Y.

Another model that concerns the data was developed for Poland, as outlined in Table 3. However, as the previous GDP was used, this section focuses on Gross National Income, as the X_1 variable influences the share of renewable energy sources in the gross marginal energy consumption as the Y variable.

Table 3. Results of modeling the share of renewable energy sources in gross marginal energy consumption in Poland in 1991–2022 using a linear econometric model of one variable.

N = 32	R = 0.89027206, R^2 = 0.79258435, Corr. R^2 = 0.78567049 F(1.30) = 114.64, *p* < 0.00000, Std Error of Estim. 1.3094			
	Coefficients	**Standard Error**	**t-Stat**	***p* Value**
Absolute term	3.504782	0.510628	6.86367	0.00000013
GNI (X_1)	0.014364	0.001342	10.70687	0.00000000

The estimated model shows that if the X_1 variable denoting the value of GNI expressed in USD billion increases by one whole unit (USD 1 billion), the share of renewable energy sources in the gross marginal energy consumption will also increase by 14.36%. The estimated econometric model is exceptionally well suited to the empirical data and reflects the changes in this phenomenon over time to be 79.26%. In this case, the H_0 hypothesis also was rejected in favor of the alternative hypothesis H_1, which means that the structural parameter is statistically significant. The variable X_1 has a significant impact on the dependent variable Y. Completing the regression analysis, the model of the share of renewable energy sources in the gross marginal energy consumption in Poland (GNI) is presented below in Equation (2):

$$\hat{Y}_t = 3.5048 + 0.01436\, X_1 \quad (2)$$

4.2. Regression Model Based on Variable Y (Renewable) and Variable X (GDP) for Sweden

The following two regression models were developed for Sweden. To create the current model, Sweden's GDP was used as variable X_1, influencing the share of renewable energy sources in the gross marginal energy consumption as variable Y (Table 4).

Table 4. Results of modeling the share of renewable energy sources in gross marginal energy consumption in Sweden in 1991–2022 using a linear econometric model of one variable.

N = 32	R = 0.91952560, R^2 = 0.84552732, Corr. R^2 = 0.84037824 F(1.30) = 164.21, *p* < 0.00000, Std Error of Estim. 3.7974			
	Coefficients	**Standard Error**	**t-Stat**	***p* Value**
Absolute term	17.48746	2.183803	8.00780	0.00000001
GDP (X_1)	0.06423	0.005012	12.81441	0.00000000

The estimated model shows that if the variable X_1, denoting the amount of GDP expressed in USD billion, increases by one whole unit (USD 1 billion), the share of renewable energy sources in gross marginal energy consumption in Sweden would also increase by 64.2%. Such a considerable increase is no longer possible in this country due to the current share of renewable energy sources. Still, it shows how quickly the share of renewable energy in the gross marginal energy consumption grew there. The estimated econometric model is well suited to the empirical data and reflects 84.55% of the changes in this phenomenon over time. It is evidenced by the value of the coefficient R^2 = 0.8455. The actual values of the share of renewable energy sources in the gross marginal energy consumption in the following years deviate from the estimated model by 3.797% on average. In turn, the residual deviation, indicating the average deviation of the theoretical values from the arithmetic mean of empirical values, is S_e = 3.799%.

The last phenomenon presented is the importance of the structural parameters. The H_0 hypothesis was rejected in favor of the alternative H_1 hypothesis, which means that the structural parameter is statistically significant. The variable X_1 has a significant impact on the dependent variable Y. Completing the regression analysis, the model of the share of renewable energy sources in the gross marginal energy consumption in Sweden (GDP) is presented below:

$$\hat{Y}t = 17.4875 + 0.06423\ X_1 \quad (3)$$

The second of the Swedish regression models was created using the GNI of Sweden as the variable X_1, influencing the share of renewable energy sources in the gross marginal energy consumption as variable Y (Table 5).

Table 5. Results of modeling the share of renewable energy sources in gross marginal energy consumption in Sweden in 1991–2022 using a linear econometric model of one variable.

N = 32	**R = 0.91507404, R^2 = 0.83736051, Corr. R^2 = 0.83193919 F(1.30) = 154.46, p < 0.00000, Std Error of Estim. 3.8965**			
	Coefficients	**Standard Error**	**t-Stat**	***p* Value**
Absolute term	18.57016	2.167887	8.56602	0.00000001
GNI (X_1)	0.06099	0.004908	12.42807	0.00000000

The estimated model shows that if the X_1 variable denoting the value of GNI expressed in a billion USD increases by one whole unit (USD 1 billion), the share of renewable energy sources in gross marginal energy consumption in Sweden will also increase by 61%. The estimated econometric model is well suited to the empirical data and reflects 83.74% of the changes in this phenomenon over time. The last phenomenon presented shows the importance of the structural parameter α_i. In the tested example, α = 0.05, the p value, as shown in Table 5, is a minimal value, and its first number is at the 9th decimal place. This dependence shows that the H_0 hypothesis was rejected, favoring the H1 alternative hypothesis, which means that the structural parameter is statistically significant. The variable X_1 has a significant impact on the dependent variable Y. Completing the regression analysis, the model of the share of renewable energy sources in gross marginal energy consumption in Sweden (GNI) is presented below:

$$\hat{Y}_t = 18.5702 + 0.06099\ X_1 \quad (4)$$

4.3. Regression Model Based on GDP (Variable Y) and Renewable (Variable X_1) for Poland and Sweden

The last analyzed dependence is the opposite situation to the previous two items. The current model was created using the share of renewable energy sources in the gross marginal energy consumption as the X_1 variable influencing the size of the Gross Domestic Product as the dependent variable Y. The model illustrating this situation in both Poland

and Sweden is detailed below. In the analyzed example, all the necessary data for Poland is presented in Table 6 and for Sweden in Table 7.

Table 6. The results of modeling the Gross Domestic Product in Poland in 1991–2022 using a linear econometric model of one variable.

N = 32	**R = 0.89383973, R^2 = 0.79894947, Corr. R^2 = 0.79224778 F(1.30) = 119.22, p < 0.00000, Std Error of Estim. 84.617**			
	Coefficients	**Standard Error**	**t-Stat**	***p* Value**
Absolute term	−139.929	47.43734	−2.94976	0.006114
RES share (X_1)	58.669	5.37327	10.91862	0.000000

Table 7. The results of modeling the Gross Domestic Product in Sweden in 1991–2022 using a linear econometric model of one variable.

N = 32	**R = 0.91952560, R^2 = 0.84552732, Corr. R^2 = 0.84037824 F(1.30) = 164.21, p < 0.00000, Std Error of Estim. 54.363**			
	Coefficients	**Standard Error**	**t-Stat**	***p* Value**
Absolute term	−166.160	46.32738	−3.58665	0.001172
RES share (X_1)	13.164	1.02727	12.81441	0.000000

The estimated model shows that if the variable X_1, denoting the share of renewable energy sources in Poland's gross marginal energy consumption expressed in %, increases by one whole unit (1%), GDP will increase by USD 58.67 billion. The estimated econometric model is exceptionally well suited to the empirical data, and at 79.89%, it reflects the change in this phenomenon over time as in the inverse case where GDP was the variable Y. On the other hand, the residual deviation, representing the average deviation of the theoretical values from the arithmetic mean of empirical values, was Se = USD 84.62 billion. The last phenomenon presented is the importance of the structural parameter α_i. The H_0 hypothesis was rejected in favor of the alternative H1 hypothesis, which means that the structural parameter is statistically significant. The variable X_1 has a significant impact on the dependent variable Y. Complementing the regression analysis below, the model of the Gross Domestic Product in Poland, depending on the share of renewable energy sources, is presented in the gross marginal energy consumption (see Equation (5)):

$$\hat{Y}_t = -139.93 + 58.669\ X_1 \tag{5}$$

In turn, the situation in Sweden is mentioned in Table 7.

The estimated model shows that if the variable X_1 representing the share of renewable energy sources in Sweden's gross marginal energy consumption expressed in % increases by one whole unit (1%), GDP would increase by USD 13.16 billion. The estimated econometric model is exceptionally well suited to the empirical data and at 84.55% reflects the change of this phenomenon over time as in the inverse case where GDP was the variable Y. The H_0 hypothesis was rejected in favor of the H1 alternative hypothesis, which means that the structural parameter is statistically significant and the variable X_1 has a significant impact on the dependent variable Y. Completing the regression analysis, the model of Gross Domestic Product in Sweden, depending on the share of renewable energy sources in gross marginal energy consumption, is formulated using Equation (6):

$$\hat{Y}_t = -166.16 + 13.164\ X_1 \tag{6}$$

To sum up, positive correlation between GDP and GNI variables (which is statistically significant) for Sweden (84.6% and 83.7%, respectively) and Poland (79.9% and 79.2%, respectively) influences the use of renewable energy sources. The findings of the study reveal the importance of RES use in the leading countries but simultaneously the paper points that the risk of recession is higher in these economies in comparison to less-income countries.

5. Discussion

The results of this research fill in the research gap concerning the renewables share in highly developed and developed countries. The comparative analysis made it possible to compare the fundamental indicators of economic growth (GDP, GNI) with the use of a regression model. The research conducted by the authors of the paper confirm the need of disseminating the knowledge about RES and its use by different economies. The current state of research concerning the problem still seems to be verified in order to provide evidence on the importance of the problem and correlations between the analyzed coefficients. The research conducted by the authors partially confirm the positive and dynamic impact of renewables on the GDP and GNI of the countries. Additionally, economic recession can constitute a danger for well-developed countries [33]. The higher economic growth caused by the use of renewables is possible but in time the risk of a greater recession is much more possible than in other countries simultaneously.

Answering the first research question, there is a positive relationship between the share of RES in gross marginal energy consumption and economic growth. The higher the economic growth, the more often renewables are used in the countries because they play a significant role in building the economic growth of their economies. In the situation when the GDP and GNI are lower, renewable energy sources are less often used by the government of the country. Another relationship (second question) was to investigate whether the variables interact with each other in the regression model. A critical issue that has been concluded from the analysis of the regression model used in the research is that the more RES-addicted the economy, the worse the situation of the country (in case of any economic crisis and fluctuations). In the situation of economic recession, the country feels the effects of the RES share decrease more often than other less RES-addicted countries. It can be confirmed by the research because it was observed in the results and correlations. Because the study is an attempt to disseminate effects on the structure of the energy sector data, the regression models are presented in a comparative form in Table 8. The bold text indicates the most favorable values. For example, the model for Poland, where the dependent Y variable (RES) distinguished the share of renewable energy sources in gross marginal energy consumption, was compared using the explanatory variable. Concerning GDP (X_1), the model was better adjusted to empirical data, and the reflection of the change of this phenomenon overtime was more favorable. The situation with the standard error of estimation was similarly more favorable because the value was lower than when explaining RES using GNI, which meant that the actual values deviated from the estimated model. On the other hand, in the case of estimating the Y variable with the GNI variable (X_1), there was a higher increase in the Y variable when the X_1 variable increased by one unit (USD billion). However, based on available information, the regression model exhibiting the modeling of the share of renewable energy sources in gross marginal energy consumption in Poland in 1991–2022, with the use of the linear econometric model, is accurately estimated by the Gross Domestic Product due to the lower error.

Table 8. Summary of the regression models.

Summary	Increase of the X_1 Variable by One Unit Causes an Increase in the Dependent Variable by:	R^2	Standard Error of Estimation:	Significance of the F Statistics	The Importance of Structural Parameters	Correlation
Poland						
RES (Y), GDP (X_1)	13.618%	0.798949	1.2892%	5.86×10^{-12}	0.00000004	0.8938
RES (Y), GNI (X_1)	14.364%	0.792584	1.3094%	9.11×10^{-12}	0.00000013	0.8903
GDP (Y), RES (X_1)	58.669 billion USD	0.798949	84.617 billion USD	5.86×10^{-12}	0.00611400	0.8938
GNI (Y), RES (X_1)	55.179 billion USD	0.792584	82.763 billion USD	9.11×10^{-12}	0.01117993	0.8903
Sweden						
Summary	**Increase of the X_1 Variable by One Unit Causes an Increase in the Dependent Variable by:**	**R^2**	**Standard Error of Estimation:**	**Significance of the F Statistics**	**The Importance of Structural Parameters**	**Correlation**
RES (Y), GDP (X_1)	64.23%	0.845527	3.7974%	2.69×10^{-13}	0.00000001	0.9195
RES (Y), GNI (X_1)	60.99%	0.837360	3.8965%	2.31×10^{-13}	0.000000001	0.9151
GDP (Y), RES (X_1)	13.164 billion USD	0.845527	54.363 billion USD	2.69×10^{-13}	0.001172	0.9195
GNI (Y), RES (X_1)	13.729 billion USD	0.837360	58.897 billion USD	2.31×10^{-13}	0.00075493	0.9151

Source: Own study based on EUROSTAT and World Bank data.

Figure 5 depicts the comparison in trend analyses for both countries in terms of the economic indicators, showing their tendency to grow in the next few years. The prognosis of GDP and GNI fluctuations are positive concerning both countries. The regression model is more accurately illustrated when the dependent variable is the GDP indicator than the GNI. The model (linear econometric model of one variable) represents the creation of economic growth and development in Poland within 1991–2022 using the share of RES in the gross marginal energy consumption. The regression that models the share of renewable energy sources in the gross marginal energy consumption in Sweden in 1991–2022 through the application of a linear econometric model of one variable is also better estimated by the GDP. It is argued that there is a minor error and an adjustment of the model to the data, but also the fact that an increase in GDP by one unit (USD billion) causes a greater increase in the share of RES compared to GNI The regression model (linear econometric model of one variable) presenting the creation of economic growth and development in Sweden, with the use of renewable energy sources in the gross marginal energy consumption, is better illustrated when the dependent variable is GDP than GNI. However, despite the above selection between GDP and GNI, both variables affect the RES variable to a similar extent, and RES describe both similarly. The RES variable is statistically significant for the regression model. The positive correlation between the share of renewable energy sources in the gross final energy consumption and GDP in Poland was 0.89384, whereas in Sweden the correlation equaled 0.91953. Considering the correlation between the share of renewable energy sources in the gross final energy consumption and GNI, the research shown that it was a positive correlation in Poland (0.89027) and in Sweden (0.91507). The variable determining the share of renewable energy sources significantly influences the shaping of the variable denoting economic growth (GDP and GNI) in Poland and Sweden. Considering the lower ex-ante error, a better fit is characteristic for the model with the GDP variable. The variable determining economic growth (GDP and GNI) significantly influences the shape of the variable determining the share of renewable energy sources in Poland and Sweden. These results are consistent with the data presented in the Global Renewables Outlook report, which emphasizes that the increase in expenditure on "green" transformation leads to faster global GDP growth—by 2.4% more than with the current plans (IRENA 2020). Investments in renewable energy sources should increase economic growth and the number of jobs.

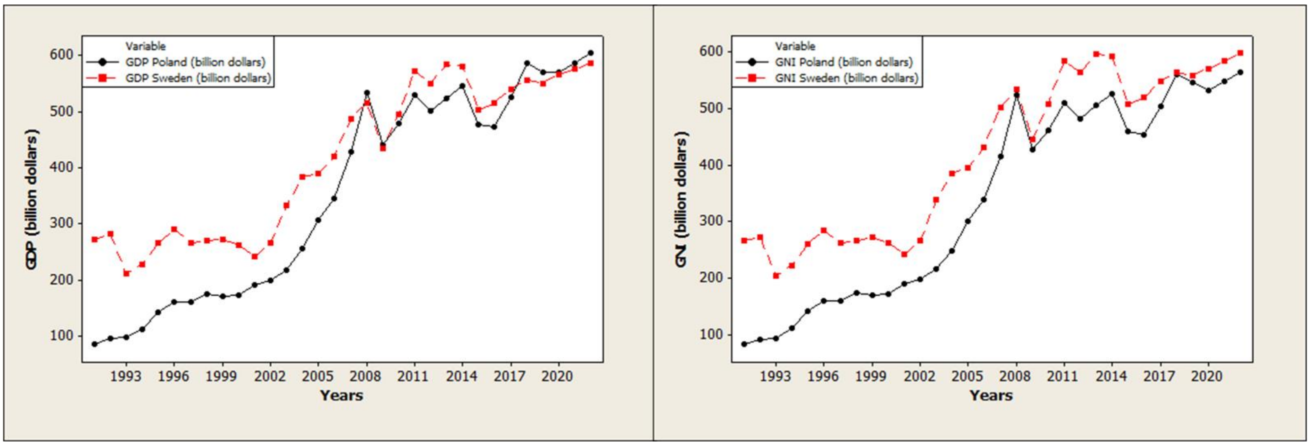

Figure 5. Comparison of GDP vs. GNI for Poland and Sweden between 1991 and 2022.

The analysis of linear regression made it possible to predict the value of one variable (GDP, GNI) on the basis of the other variable (RES). Thanks to this method, the analyzed countries may make optimal decisions concerning RES use and how it influences their economic growth. Moreover, thanks to data analysis and with the use of a linear regression model, the decision-makers of the countries now have an in-depth analysis and presentation of the new models and relations between coefficients.

Energy Policy Implication and Future Agenda for Economic Growth

The statistical differences between countries should be on display by the governments' decision-makers to mainstream this into energy policy within the EU. It should help align these differences in economic values between less-income Polish and high-income Swedish economies. Moreover, those issues will be most significant for small and medium enterprises, which account for the generation for 29% of the added values in Poland [65] versus more than 61% in the Swedish "non-financial business economy" [66]. The consequences of lack of coherence and unified EU energy policy leads to a gap in the relevant literature and prompts to examine forecasting models or tools for applying energy policy in practice. A discussion on energy policy research cannot be separated from the macroeconomic determinants. Therefore, research must be addressed to the factors of unified energy policy to set energy targets for European countries, and then make interventions in order to meet the goals and targets that influence the nation's energy demand. In this context, it would be a crucial agenda of the EU governments by restructuring the content of the current, incoherent energy policy. Element such as economic impact of energy prices and cost-effective investment in RES should be supported adequately by politicians and decision-makers, thereby becoming competitive [67].

In line with the abovementioned finding, some energy policy implications can be recommended for managing the RES energy demand:

- Energy efficiency improvements in the EU countries by implementation of technological innovations. Thanks to that, a balance in the macroeconomic factors between these countries could be maintained.
- Supportive initiatives to promote the reduction dependency on fossil fuels, especially in Poland, and permanent diversification its energy mix by augmenting renewable energy resources.
- Fiscal and tax policies make them particularly essential to examine the negative or positive impact of macroeconomic factors.
- Research models and methods towards facilitating management and evaluation should be able to use existing energy data to generate statistical reports available

for the public institutions. They might be necessary to analyze energy-related trends and provide sufficient indicators for newest technological initiatives.

A transformation into sustainable energy and infrastructure in the post-COVID-19 time through different models is needed in the next few years to provide sustainable economies while ensuring equitable energy planning for economic growth [68].

6. Conclusions

The goal of the study was achieved by depicting the positive correlations between energy-related variables on the level of economic growth in Poland and Sweden. Economic growth and development as well as the share of renewable energy sources in gross marginal energy consumption [69] are the variables between which mutual interaction occurs both these countries. The positive correlations observed between these variables were characterized by the fact that the increase in gross marginal energy consumption contributes to the increase in economic growth. The share of RES could be increased drastically by taking actions to accelerate the economic growth in less-developed countries and promoting national initiatives. The calculation of correlations revealed that in Sweden there was the largest gap (0.44%) between its GDP and GNI compared to Poland (0.35%). In general, in Sweden the impact of RES on GDP is higher by about 2.57% in comparison to Poland, and greater by 2.48% given the RES–GNI analysis.

The results confirm also that the long-term perspective of the economic growth of those developed countries in terms of GDP depends on energy consumption from renewables. The results achieved do not support the research done in [38]. Therefore, developing countries are making more efforts to replace fossil fuels and reduce their dependence by investing in renewable energy resources [6]. The pandemic could change the values of the economic variables only temporarily and in the long run shift to focus on the growth relationship (energy-GDP and energy-GNI). Therefore, the pandemic might result in a significant decrease in all the parameters. The study seems to be unique through mapping of the correlation effects on the structure of the energy sector across the last 20 years, shifting from a traditional fossil-based economy into a renewables-based economy. It, in turn, makes this research different from other studies and fill a gap in the present literature and statistical reports. This paper provides new insight for further research on other countries that are differentiated in terms of economic growth, income, and use of RES. The in-depth analysis could focus on renewable energy sources that impact not only on GDP and GNI but also on other economic quantitative (Net National Income—NNI, inflation rate, GDP per capita, budget deficit, etc.) and qualitative (Human Development Index—HDI, Human Poverty Index—HPI, extent of investments, etc.) indicators.

Moreover, this paper highlights the fundamentals for further research in the area of using renewable energy sources in all European Union countries, taking the abovementioned economic indicators into account.

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References

1. Yang, L.; Wang, X.-C.; Dai, M.; Chen, B.; Qiao, Y.; Deng, H.; Zhang, D.; Zhang, Y.; Almeida, C.; Chou, A.; et al. Shifting from Fossil-Based Economy to Bio-Based Economy: Status Quo, Challenges, and Prospects. *Energy* **2021**, *228*, 120533. [CrossRef]
2. IRENA. *Renewable Power Generation Costs in 2019*; IRENA: Abu Dhabi, United Arab Emirates, 2020.
3. Shabbir, M.S.; Muhammad, I. The Dynamic Impact of Foreign Portfolio Investment on Stock Prices in Pakistan. *Transnatl. Corp. Rev.* **2019**, *11*, 166–178. [CrossRef]
4. Shabbir, M.S.; Wisdom, O. The Relationship between Corporate Social Responsibility, Environmental Investments and Financial Performance: Evidence from Manufacturing Companies. *Environ. Sci. Pollut. Res.* **2020**, *27*, 39946–39957. [CrossRef]
5. Wang, Z.; Danish; Zhang, B.; Wang, B. Renewable Energy Consumption, Economic Growth and Human Development Index in Pakistan: Evidence Form Simultaneous Equation Model. *J. Clean. Prod.* **2018**, *184*, 1081–1090. [CrossRef]
6. Ozcan, B. Renewable Energy Consumption-Economic Growth Nexus in Emerging Countries: A Bootstrap Panel Causality Test. *Renew. Sustain. Energy Rev.* **2019**, *104*, 30–37. [CrossRef]
7. Destek, M.A.; Sinha, A. Renewable, Non-Renewable Energy Consumption, Economic Growth, Trade Openness and Ecological Footprint: Evidence from Organisation for Economic Co-Operation and Development Countries. *J. Clean. Prod.* **2020**, *242*, 118537. [CrossRef]
8. Nasreen, S.; Anwar, S.; Ozturk, I. Financial Stability, Energy Consumption and Environmental Quality: Evidence from South Asian Economies. *Renew. Sustain. Energy Rev.* **2017**, *67*, 1105–1122. [CrossRef]
9. Muhammad, I.; Shabbir, M.; Saleem, S.; Bilal, K.; Ulucak, R. Nexus between Willingness to Pay for Renewable Energy Sources: Evidence from Turkey. *Environ. Sci. Pollut. Res. Int.* **2021**, *28*, 2972–2986. [CrossRef]
10. Khuong, N.V.; Shabbir, M.S.; Sial, M.S.; Khanh, T.H.T. Does Informal Economy Impede Economic Growth? Evidence from an Emerging Economy. *J. Sustain. Financ. Invest.* **2021**, *11*, 103–122. [CrossRef]
11. Murshed, M.; Alam, M. An Estimation of the Macroeconomic Determinants Total, Renewable and Non-Renewable Energy Demands in Bangladesh: The Role of Technological Innovations. *Environ. Sci. Pollut. Res.* **2021**, *28*, 30176–30196. [CrossRef]
12. Aslan, A.; Öcal, O. The Role of Renewable Energy Consumption in Economic Growth: Evidence from Asymmetric Causality. *Renew. Sustain. Energy Rev.* **2016**, *60*, 953–959. [CrossRef]
13. Apergis, N.; Chang, T.; Gupta, R.; Ziramba, E. Hydroelectricity Consumption and Economic Growth Nexus: Evidence from a Panel of Ten Largest Hydroelectricity Consumers. *Renew. Sustain. Energy Rev.* **2016**, *62*, 318–325. [CrossRef]
14. Bhattacharya, M.; Paramati, S.R.; Ozturk, I.; Bhattacharya, S. The Effect of Renewable Energy Consumption on Economic Growth: Evidence from Top 38 Countries. *Appl. Energy* **2016**, *162*, 733–741. [CrossRef]
15. Bildirici, M.E.; Gökmenoğlu, S.M. Environmental Pollution, Hydropower Energy Consumption and Economic Growth: Evidence from G7 Countries. *Renew. Sustain. Energy Rev.* **2017**, *75*, 68–85. [CrossRef]
16. Armeanu, D.Ş.; Vintilă, G.; Gherghina, Ş.C. Does Renewable Energy Drive Sustainable Economic Growth? Multivariate Panel Data Evidence for EU-28 Countries. *Energies* **2017**, *10*, 381. [CrossRef]
17. Bilgili, F.; Ozturk, I. Biomass Energy and Economic Growth Nexus in G7 Countries: Evidence from Dynamic Panel Data. *Renew. Sustain. Energy Rev.* **2015**, *49*, 132–138. [CrossRef]
18. Pegkas, P. The Impact of Renewable and Non-Renewable Energy Consumption on Economic Growth: The Case of Greece. *Int. J. Sustain. Energy* **2020**, *39*, 380–395. [CrossRef]
19. Polish Economic Institute. Poland ranks 32nd in the Responsible Development Index. In Polish: Polska na 32. Miejscu w Indeksie Odpowiedzialnego Rozwoju. Available online: https://www.thefirstnews.com/article/poland-ranks-32nd-in-responsible-development-index---economic-institute-15743 (accessed on 20 December 2021).
20. Sachs, J.; Kroll, C.; Lafortune, G.; Fuller, G. *The Sustainable Development Goals and COVID-19: Includes the SDG Index and Dashboards*; Sustainable Development Report; Cambridge University Press: Cambridge, UK, 2021; ISBN 978-1-108-83420-9.
21. Muñoz-La Rivera, F.; Hermosilla, P.; Delgadillo, J.; Echeverría, D. The Sustainable Development Goals (SDGs) as a Basis for Innovation Skills for Engineers in the Industry 4.0 Context. *Sustainability* **2020**, *12*, 6622. [CrossRef]
22. Ben Jebli, M.; Ben Youssef, S. The Environmental Kuznets Curve, Economic Growth, Renewable and Non-Renewable Energy, and Trade in Tunisia. *Renew. Sustain. Energy Rev.* **2015**, *47*, 173–185. [CrossRef]
23. Menegaki, A.N.; Tugcu, C.T. Energy Consumption and Sustainable Economic Welfare in G7 Countries; A Comparison with the Conventional Nexus. *Renew. Sustain. Energy Rev.* **2017**, *69*, 892–901. [CrossRef]
24. Menegaki, A.; Tiwari, A. The Index of Sustainable Economic Welfare in the Energy-Growth Nexus for American Countries. *Ecol. Indic.* **2017**, *72*, 494–509. [CrossRef]
25. Amri, F. Intercourse across Economic Growth, Trade and Renewable Energy Consumption in Developing and Developed Countries. *Renew. Sustain. Energy Rev.* **2017**, *69*, 527–534. [CrossRef]
26. Bulut, U.; Inglesi-Lotz, R. Which Type of Energy Drove Industrial Growth in the US from 2000 to 2018? *Energy Rep.* **2019**, *5*, 425–430. [CrossRef]
27. Quitzow, R.; Bersalli, G.; Eicke, L.; Jahn, J.; Lilliestam, J.; Lira, F.; Marian, A.; Süsser, D.; Thapar, S.; Weko, S.; et al. The COVID-19 Crisis Deepens the Gulf between Leaders and Laggards in the Global Energy Transition. *Energy Res. Soc. Sci.* **2021**, *74*, 101981. [CrossRef]
28. Khanna, M. COVID-19: A Cloud with a Silver Lining for Renewable Energy? *Appl. Econ. Perspect. Policy* **2021**, *43*, 73–85. [CrossRef]

29. IEA Global Energy Review 2020—Analysis and Key Findings. A Report by the International Energy Agency. Available online: https://www.iea.org/reports/global-energy-review-2020 (accessed on 23 November 2021).
30. Werth, A.; Gravino, P.; Prevedello, G. Impact Analysis of COVID-19 Responses on Energy Grid Dynamics in Europe. *Appl. Energy* **2021**, *281*, 116045. [CrossRef]
31. Dharani, M.; Hassan, M.K.; Rabbani, M.R.; Huq, T. Does the COVID-19 Pandemic Affect Faith-Based Investments? Evidence from Global Sectoral Indices. *Res. Int. Bus. Financ.* **2022**, *59*, 101537. [CrossRef]
32. Alam, M.N.; Alam, M.S.; Chavali, K. Stock Market Response during COVID-19 Lockdown Period in India: An Event Study. *J. Asian Financ. Econ. Bus.* **2020**, *7*, 131–137. [CrossRef]
33. Kilpeläinen, S. Developing Nordic Cooperation in Renewable Electricity Policy: Exploring Views from Finland and Sweden. *Politics Gov.* **2020**, *8*, 44–52. [CrossRef]
34. Spasova, D.; Braungardt, S. Building a Common Support Framework in Differing Realities—Conditions for Renewable Energy Communities in Germany and Bulgaria. *Energies* **2021**, *14*, 4693. [CrossRef]
35. Keček, D.; Mikulić, D.; Lovrinčević, Ž. Deployment of Renewable Energy: Economic Effects on the Croatian Economy. *Energy Policy* **2019**, *126*, 402–410. [CrossRef]
36. Miškinis, V.; Galinis, A.; Konstantinavičiūtė, I.; Lekavičius, V.; Neniškis, E. The Role of Renewable Energy Sources in Dynamics of Energy-Related GHG Emissions in the Baltic States. *Sustainability* **2021**, *13*, 10215. [CrossRef]
37. Tanil, G.; Jurek, P. Policies on Renewable Energy at the European and National Level of Governance: Assessing Policy Adaptation in the Czech Republic. *Energy Rep.* **2020**, *6*, 548–553. [CrossRef]
38. Menegaki, A.N. Growth and Renewable Energy in Europe: A Random Effect Model with Evidence for Neutrality Hypothesis. *Energy Econ.* **2011**, *33*, 257–263. [CrossRef]
39. Kasman, A.; Duman, Y.S. CO_2 Emissions, Economic Growth, Energy Consumption, Trade and Urbanization in New EU Member and Candidate Countries: A Panel Data Analysis. *Econ. Model.* **2015**, *44*, 97–103. [CrossRef]
40. Presno, M.J.; Landajo, M. EU-28's Progress toward the 2020 Renewable Energy Share: A Club Convergence Analysis. *Environ. Sci. Pollut. Res.* **2021**, *28*, 66830–66844. [CrossRef]
41. Salim, R.A.; Rafiq, S. Why Do Some Emerging Economies Proactively Accelerate the Adoption of Renewable Energy? *Energy Econ.* **2012**, *34*, 1051–1057. [CrossRef]
42. Omri, A.; Daly, S.; Nguyen, D.K. A Robust Analysis of the Relationship between Renewable Energy Consumption and Its Main Drivers. *Appl. Econ.* **2015**, *47*, 2913–2923. [CrossRef]
43. Irandoust, M. The Renewable Energy-Growth Nexus with Carbon Emissions and Technological Innovation: Evidence from the Nordic Countries. *Ecol. Indic.* **2016**, *69*, 118–125. [CrossRef]
44. Soava, G.; Mehedintu, A.; Sterpu, M.; Raduteanu, M. Impact of Renewable Energy Consumption on Economic Growth: Evidence from European Union Countries. *Technol. Econ. Dev. Econ.* **2018**, *24*, 914–932. [CrossRef]
45. Radmehr, R.; Henneberry, S.R.; Shayanmehr, S. Renewable Energy Consumption, CO_2 Emissions, and Economic Growth Nexus: A Simultaneity Spatial Modeling Analysis of EU Countries. *Struct. Chang. Econ. Dyn.* **2021**, *57*, 13–27. [CrossRef]
46. Lee, J.W. Long-Run Dynamics of Renewable Energy Consumption on Carbon Emissions and Economic Growth in the European Union. *Int. J. Sustain. Dev. World Ecol.* **2019**, *26*, 69–78. [CrossRef]
47. Li, Q.; Cherian, J.; Shabbir, M.; Sial, M.; Li, J.; Mester, I.; Badulescu, A. Exploring the Relationship between Renewable Energy Sources and Economic Growth. The Case of SAARC Countries. *Energies* **2021**, *14*, 520. [CrossRef]
48. Al-Mulali, U.; Fereidouni, H.G.; Lee, J.Y.M. Electricity Consumption from Renewable and Non-Renewable Sources and Economic Growth: Evidence from Latin American Countries. *Renew. Sustain. Energy Rev.* **2014**, *30*, 290–298. [CrossRef]
49. Magazzino, C.; Mele, M.; Morelli, G. The Relationship between Renewable Energy and Economic Growth in a Time of COVID-19: A Machine Learning Experiment on the Brazilian Economy. *Sustainability* **2021**, *13*, 1285. [CrossRef]
50. Afsharzade, N.; Papzan, A.; Ashjaee, M.; Delangizan, S.; Passel, S.; Azadi, H. Renewable Energy Development in Rural Areas of Iran. *Renew. Sustain. Energy Rev.* **2016**, *65*, 743–755. [CrossRef]
51. Gökgöz, F.; Güvercin, M.T. Energy Security and Renewable Energy Efficiency in EU. *Renew. Sustain. Energy Rev.* **2018**, *96*, 226–239. [CrossRef]
52. Adom, P.K.; Amuakwa-Mensah, F.; Agradi, M.P.; Nsabimana, A. Energy Poverty, Development Outcomes, and Transition to Green Energy. *Renew. Energy* **2021**, *178*, 1337–1352. [CrossRef]
53. Chen, K.; Wang, M.; Huang, C.; Kinney, P.; Anastas, P. Air Pollution Reduction and Mortality Benefit during the COVID-19 Outbreak in China. *Lancet Planet. Health* **2020**, *4*, e210–e212. [CrossRef]
54. Kuzemko, C.; Bradshaw, M.; Bridge, G.; Goldthau, A.; Jewell, J.; Overland, I.; Scholten, D.; Van de Graaf, T.; Westphal, K. COVID-19 and the Politics of Sustainable Energy Transitions. *Energy Res. Soc. Sci.* **2020**, *68*, 101685. [CrossRef]
55. Aruga, K.; Islam, M.M.; Jannat, A. Effects of COVID-19 on Indian Energy Consumption. *Sustainability* **2020**, *12*, 5616. [CrossRef]
56. Bahmanyar, A.; Estebsari, A.; Ernst, D. The Impact of Different COVID-19 Containment Measures on Electricity Consumption in Europe. *Energy Res. Soc. Sci.* **2020**, *68*, 101683. [CrossRef]
57. Hosseini-Fashami, F.; Motevali, A.; Nabavi-Pelesaraei, A.; Hashemi, S.J.; Chau, K. Energy-Life Cycle Assessment on Applying Solar Technologies for Greenhouse Strawberry Production. *Renew. Sustain. Energy Rev.* **2019**, *116*, 109411. [CrossRef]
58. Eroğlu, H. Effects of COVID-19 Outbreak on Environment and Renewable Energy Sector. *Environ. Dev. Sustain.* **2021**, *23*, 4782–4790. [CrossRef]

59. Bhuiyan, M.A.; An, J.; Mikhaylov, A.; Moiseev, N.; Danish, M.S.S. Renewable Energy Deployment and COVID-19 Measures for Sustainable Development. *Sustainability* **2021**, *13*, 4418. [CrossRef]
60. WEF. *Fostering Effective Energy Transition*; Insight Report, 2020 Edition; WEF: Cologny, Switzerland, 2020.
61. *PEP2040 Energy Policy of Poland until 2040*; Extract; Ministry of Climate and Environment: Warsaw, Poland, 2021.
62. Fu, Q.; Álvarez-Otero, S.; Sial, M.S.; Comite, U.; Zheng, P.; Samad, S.; Oláh, J. Impact of Renewable Energy on Economic Growth and CO2 Emissions—Evidence from BRICS Countries. *Processes* **2021**, *9*, 1281. [CrossRef]
63. Shahbaz, M.; Loganathan, N.; Zeshan, M.; Zaman, K. Does Renewable Energy Consumption Add in Economic Growth? An Application of Auto-Regressive Distributed Lag Model in Pakistan. *Renew. Sustain. Energy Rev.* **2015**, *44*, 576–585. [CrossRef]
64. Ntanos, S.; Skordoulis, M.; Kyriakopoulos, G.; Arabatzis, G.; Chalikias, M.; Galatsidas, S.; Batzios, A.; Katsarou, A. Renewable Energy and Economic Growth: Evidence from European Countries. *Sustainability* **2018**, *10*, 2626. [CrossRef]
65. Czerniak, A.; Stefański, M. *Small and Medium Enterprises in Poland—Obstacles and Development*; Polityka Insight Research 2021; Polityka Insight: Warsaw, Poland, 2021.
66. European Commission. *2019 SBA Fact Sheet & Scoreboard*; European Commission: Brussels, Belgium, 2019.
67. Sorrell, S. Reducing Energy Demand: A Review of Issues, Challenges and Approaches. *Renew. Sustain. Energy Rev.* **2015**, *47*, 74–82. [CrossRef]
68. Manigandan, P.; Alam, M.S.; Alharthi, M.; Khan, U.; Alagirisamy, K.; Pachiyappan, D.; Rehman, A. Forecasting Natural Gas Production and Consumption in United States-Evidence from SARIMA and SARIMAX Models. *Energies* **2021**, *14*, 6021. [CrossRef]
69. Matei, I. Is There a Link between Renewable Energy Consumption and Economic Growth? A Dynamic Panel Investigation for the OECD Countries. *Rev. D'economie Polit.* **2017**, *127*, 985–1012. [CrossRef]

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Article

CSR in Poland and the Implementation of Sustainable Development Goals in the Energy Sector during the COVID-19 Pandemic †

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† Following the World Health Organization, we assume that the term "epidemic" means the occurrence of a much higher number of infectious diseases in an area, than in the previous period, or the sudden outbreak of an infectious disease that has never occurred. The occurrence of an epidemic at a certain point given time, caused by the same pathogen, is called a pandemic in many countries and even on continents. Therefore, it makes sense to use both terms in COVID-19, and this is the solution we used in our study. However, if the conditions are international (which is often the case in the energy sector), then we use the term pandemic, which is a common solution.

Abstract: The aim of this paper was to examine whether the COVID-19 epidemic has slowed the fulfilment of one of the core tasks of the energy sector "Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All" (SDG7) taking into account corporate social responsibility. Four research questions and hypotheses were posed, relating to the perspectives of local authorities, the activities of large energy companies, the impact of the epidemic on the implementation of the SDG7 and, in addition, to the understanding of CSR principles from the point of view of ordinary entrepreneurs. A qualitative descriptive analysis based on two reliable databases and a survey procedure (Question 4) was used to answer the research questions posed. The goal was achieved by positively confirming three hypotheses and testing one negatively, relating to COVID-19's slowing role in SDG7 implementation. The analysis showed that the 2020–2021 epidemic in Poland has led to more initiatives in this area, contrary to expectations. However, they were linked to the simultaneous implementation of other SDGs, which distorted their importance for achieving Goal 7. In summary, although energy companies were more active than expected during the epidemic, they had a low contribution to SDG 7. This also applies to local authorities. An analysis of the knowledge about CSR in a group of entrepreneurs from the Lublin district (case study) confirmed the opinion appearing in the literature about the lack of understanding of the concept and the need for its application.

Keywords: COVID-19; renewable energy; energy efficiency; corporate social responsibility; CSR; sustainable development goals; SDG; Poland

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1. Introduction

Over the past 25 years, the realities of the energy sector have changed in response to new market, geopolitical, social, technical, environmental and lastly health conditions [1]. With demographic pressures, a culture of overproduction and the short-term sustainability of products encouraging increased consumerism, many environmental and social indicators have been adversely affected to an alarming degree. Hence, the necessity to protect the climate and the environment, including by striving for the widespread use of low- and zero-emission sources. The Kyoto Protocol, and then the Paris Agreement, gave the European Union impetus and direction in shaping its climate and energy policy. Initially, the EU took on the challenge of meeting the so-called 3 × 20 targets, under which the EU committed to achieving a 20% share of renewables in gross final energy consumption, a

20% improvement in energy efficiency and a 20% reduction in greenhouse gas emissions. In 2014, the European Council continued its efforts to combat climate change and approved further targets for 2030, which, after revisions in 2018 and 2020, committed the EU as a whole to reduce greenhouse gas emissions by at least 55% from 1990 emissions; increase the share of renewable sources in gross final energy consumption to at least 32%, a 32.5% increase in energy efficiency; and the completion of the EU's internal energy market. In December 2020, the EU declared intent to achieve climate neutrality by 2050. However, Poland has pledged to achieve at least a 23% share of energy from renewable energy sources (RES) in gross final energy consumption by 2030, a 23% improvement in **energy efficiency** (as a reduction in primary energy consumption compared to PRIMES2007 projections) and a 30% reduction in greenhouse gas emissions compared to 1990. In 2021, negotiations began on the "Fit for 55" legislative package, which will make the 55% greenhouse gas emissions reduction target for 2030 more operational by accelerating the development of renewable energy sources and increasing energy efficiency. On 2 February 2021, the Council of Ministers adopted the landmark Energy Policy of Poland until 2040 (PEP2040). For the first time in a long-term government strategy for the energy sector, a path to a zero-carbon energy system has appeared. PEP2040 is also the first government document to record a date for closing coal until 2049 [2]. As late as 2019, Gawlik and Mokrzycki criticised Poland's preparations for the necessary change in the energy structure as one of the arguments, citing the statement that "in contrast to many European countries, the Polish government is not considering coal phase-out" [1,3]. The situation in this respect is changing rapidly not exceptionally in Poland and not only because of the implementation of the planned changes initiated by the European Union. The COVID-19 outbreak, which began in Poland on 4 March 2020 with the first case of the disease proved to be a distraction to the planned changes, including in the energy sector. The crises have had an impact both in the private and in the entrepreneurial sphere. The COVID-19 pandemic is considered a case of cumulative risk with far-reaching consequences [4], both as a natural disaster and as a financial crisis combined into one [5]. The response of financial markets to COVID-19 was shown to resemble the response to the previous financial crisis, rather than previous pandemics [6].

Without going into the biological nature of the disease-causing, ever-changing virus SARS-CoV-2, and given the topic of this paper, it is worth noting there were six apparent epidemic waves in Poland. The most dramatic were the first two: the world's surprising first wave from March to summer 2020 and the second wave from September 2020 to January 2021, when almost 1,422,000 people fell ill with COVID-19, and 35,135 died. The third wave began on 10 February 2021 (while the revival of cases began), and by the end of May, there were 1,315,000 coronavirus cases with a mortality rate of 34,333. This wave was much more violent—it lasted for a shorter period of time but collected a similar number of fatalities. The record day in terms of the number of daily COVID-19 cases was 1 April 2021, when 35,251 people became ill. A week later, a record number of deaths during the entire epidemic was recorded—954. The fourth wave, like the second, had a slower progression after the vaccinations, and before it expired for good, a new variant of the Omicron coronavirus appeared and the number of cases began to rapidly rise, creating a fifth active wave by June 2022 [7]. The sixth epidemic wave started at the end of July 2022. For entrepreneurs and businesses, this wave was associated with a previously unknown threat, both to the individual and to the economy (those who remembered previous major epidemics, such as the Spanish flu after the First World War, have already died). The rapid introduction of severe economic restrictions slowed the epidemic; it has also severely constrained economic activity and overestimated the country's physical and infrastructural goals and needs. In view of the organisational shortcomings at State level, citizens and especially large companies participated in the aid, offering mainly material and material aid [8]. In terms of citizens' health, the country's second-largest epidemic was worse due to the conflict between health and economic protection (in terms of reintroducing restrictions on business activity). Other waves accompanied by a high number of deaths occurred when vaccination against COVID-19 was already available. The high number of deaths affected people who refused vaccination, but also the limited human resources of hospitals and the availability of medical care for diseases other than SARS-CoV-2 [9,10]. While the media in the first wave cited numerous examples of support for hospitals and medical staff by organisations, there was only sporadic information in the second wave. However, that does not mean that this help did not exist; it was not driven as it was at the beginning of the pandemic.

For energy companies, active participation in the fight against the COVID-19 epidemic in the country is not a statutory activity but can take place within the framework of the pillars of corporate social responsibility and also in the context of the implementation of the Sustainable Development Goals, in particular SDG 3 "good health and wellbeing". However, it must be emphasised that each of the 17 SDG targets includes practices that contribute to improving people's quality of life through direct or indirect impact on our health. In the first year of the 2020 pandemic, Poland recorded a 40% increase in voluntarily reported good practices in the area of CSR, many of which related to the implementation of SDG 3. The financial, trade and energy sectors were the most active [8].

The paper is structured as follows: First, the authors present the situation of the Polish energy sector in the context of adaptation to the latest challenges of the climate neutrality policy in the EU and describe the main features of the COVID-19 epidemic in Poland. We formulate research goals, questions and hypotheses and show how the analysis fits into the collection of existing studies. We also explain the choice of the topic of corporate social responsibility in the energy sector. We would like to underline the need for such studies in connection with Poland's obligations in the EU and towards the world. The next step is the definition of the research method, followed by definitions and circumstances of the introduction and popularisation of concepts such as CSR and SDG, with sources of information on the activities of companies in this field in Poland. The data and results of the analysis of the four research questions are then presented. In the following sections, the authors discuss and analyse the results.

1.1. Research Goals and Questions

The analysis of the impact of the epidemic on best practices and good governance in the energy sector was based on the belief that investors consider tourism, oil and gas and the financial sector to be the most affected by COVID-19 [11].

The research goals. Bearing in mind that the outbreak of the COVID-19 pandemic could change the plans (priorities) regarding the fulfilment of corporate social responsibility tasks or slow them or delay, it seems interesting to look at CSR in the energy sector in the implementation of statutory activities of companies relating strictly to the energy sector, whose activity is included in (SDG) 7: "Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All" [12]. It is logical that in the implementation of this noble objective, the principles and rights of people and workers must be respected, and that is why we have decided to combine the "sustainable energy" plan (expressed in SDG) with the corresponding implementation of the measures taken for that purpose (good CSR practices). Broadly speaking, this can only mean the energy sector, which we want to look at from a dual perspective: the local authorities and the companies operating in the sector.

Against this background, it is useful to answer the following **research questions**:

1. To what extent are local authorities involved in the implementation of CSR good practices in the field of energy efficiency?
2. To what extent does the energy sector contribute to the implementation of CSR good practices for "access to affordable, reliable, sustainable and modern energy" (SDG 7)?
3. Has the COVID-19 outbreak reduced the involvement of companies in the implementation of SDG7?

Based on our current knowledge, we assume that:

Hypothesis 1 (H1): *Local authorities support the concept of energy efficiency, which can benefit both authorities and citizens. Implementation, however, requires considerable financial resources, which is why the measures are small steps, small initiatives.*

Hypothesis 2 (H2): *As the participation of Polish entrepreneurs in CSR is still relatively low, the involvement of the energy sector (in particular due to the difficulty in adapting to the EU's 2050 climate neutrality policy) is also expected to be low, although it refers to its priority activity in the area of affordable, clean energy. However, we have no doubt about the pro bono participation of companies in this sector.*

Hypothesis 3 (H3): *We, therefore, assume that the outbreak of the epidemic in Poland has limited the commitment to "affordable, reliable, sustainable and modern energy for all" to other ad hoc initiatives.*

Any findings confirming or disproving the low level of activity in good CSR practices can be partially commented on by answering the following question:

4. Do entrepreneurs (regardless of the sector) understand the concept of corporate social responsibility?—using the example of local companies from Lublin district (own research).

Hypothesis 4 (H4): *Given the lack of a uniform definition and the complexity of the concept [13], we assume that it may be difficult to develop a deeper understanding of the objectives and the way in which the popular concept of CSR is pursued.*

This choice of questions has, of course, its limits. First, the set does not complete the theme; second, it relies on information provided voluntarily (and, therefore, more subjectively) by organisations; and third, information on the understanding of CSR is more or less local (question 4). In addition, both the concept of corporate social responsibility and the Sustainable Development Goals are general in nature, and CSR is interpreted in different cultural contexts, both in terms of national and corporate culture. Finally, the proposed topic is highly actual, the data collected at the end of May 2022 and the connection between CSR and SDG tasks are hardly visible in the literature. This is the first empirical study on the impact of the COVID-19 epidemic on very modern concepts of responsiveness in the economic conditions of the Polish energy sector.

1.2. Selected Literature

In contrast, the COVID-19 pandemic is probably the most popular research topic in many contexts. In addition to medical research, it acts as an umbrella over place and time, activities, and interactions in other disciplines. It can be said that in many cases it is a symbol of time. That is why we have, therefore, decided not to carry out studies on many subjects under the umbrella of COVID-19 in order not to lose sight of this work. However, it is worth mentioning some of the thematically related issues, such as:

"COVID-19: What it means for the energy industry" on the PwC platform [14]—The outbreak has contributed to a decline in oil demand, resulting in plummeting oil prices and production declines, especially in the wake of the Russia–OPEC price war.

Prepared by Lu et al. [15], "Impacts of the COVID-19 epidemic on the energy sector" on the example of energy companies from the USA and China has shown that although the epidemic negatively affected many aspects of the energy industry, the pace of transition to clean energy has not stopped. However, some energy companies went bankrupt during this time.

Olabi et al. [16] "Impact of COVID-19 on the Renewable Energy Sector and Mitigation Strategies". This report examines the impact of the COVID-19 epidemic on the renewable energy (RE) sector, particularly in countries with the largest renewable electricity capacity, such as the United States, China, India and the EU. The start of renewable energy projects was interrupted due to lack of funding allocation and disruptions in the supply of equipment and components due to blocking measures. "The RE sector was [. . .] significantly impacted by the COVID-19 epidemic, but interestingly in a unique way. The power supply from REs was not affected similar to those for coal- and natural gas-fired power plants that have ceased operation or reduced operational capacity due to reduced power demand and limited fuel supply with the drop in maritime trade. The RE sector was affected mainly due to lack of capital investment and supply chain disruption, along with lockdown measures and hence reduced workforce. The COVID-19 pandemic has demanded additional budget from many governmental entities to manage such crisis and save peoples' lives; hence, less budget for capital expenditure or subsidy was available for execution of RE projects. The disruption in the supply chain has resulted in the unavailability of RE components, more specifically PV modules, either due to lockdown measures at manufacturing facilities or cessation of transportation operations, which has led to the deferral of many REs projects along with increased cost. Additionally, the lockdown measures have resulted in ceased construction work in many RE projects. [. . .] Nevertheless, the pandemic can present some opportunities once proper mitigation strategies and policy recommendations are considered for the post-COVID-19 era." (p. 569).

Werth et al. [17] in "Impact analysis of COVID-19 responses on energy grid dynamics in Europe" performed an analysis in sixteen countries. They provided results that the restrictions caused the load drop, and energy generation was affected in most countries. The results also showed that energy generation from nuclear, coal and gas sources decreased significantly, while penetration of renewables is increasing.

Siksnelyte-Butkiene [18] in "Impact of the COVID-19 Pandemic to the Sustainability of the Energy Sector" provided the systematic literature review performed in the Web of Science (WoS) database, where a total of 113 relevant articles were selected for the analysis. The five main impact areas of the COVID-19 pandemic to the sustainability of the energy sector were found: consumption and energy demand; air pollution; investments in renewable energy; energy poverty; and energy system flexibility.

About Poland "The Economic Effect of the Pandemic in the Energy Sector on the Example of Listed Energy Companies." [19] The capital groups selected for the study were: Polska Grupa Energetyczna (PGE), Tauron, Enea and Zespół Elektrowni Pątnów-Adamów-Konin (ZE PAK). These capital groups are the largest electricity producers in Poland, as they own at least one of the ten largest power plants in Poland and are listed on the stock exchange. To examine the energy effectiveness, the authors used ratio analysis tools, i.e., financial ratios, liquidity, debt, profitability and efficiency. According to the conclusions, the level of industrial production and investment declined, contributing to a decrease in domestic electricity consumption and, thus, affecting the reduction in electricity production. However, the decline in production in power plants by about 4% compared to the same period of the previous year is not significant. The pandemic accelerated the introduction of activities related to preparing entire organisations for changes to meet the challenges posed to energy companies related to decarbonisation. However, Rutkowska-Tomaszewska et al., the authors of this article, were not able to verify the actual share of RES in energy production due to the lack of figures on energy consumption by prosumers (they are not recorded).

Other works dealing with Poland and the impact of COVID-19 pandemic on selected economic aspects (other than energy) are, of course, widely represented, both as articles [20,21] and as topics of dissertations [22–24].

Of the few articles on the conjunction of CSR and SDG, the paper "Sustainable Development Goals (SDGs) as a Framework for Corporate Social Responsibility (CSR)" [25] should be highlighted, in which these two concepts were scientifically linked. Of course, we consider that the value of these ideas lies in putting them into practice. In a sense, however, there is a surplus of texts urging organisations to use them, and an excess generally leads to trivialisation. For this reason, our study focused on a database that shows already implemented good CSR practices related to the Sustainable Development Goals, not only the declared ones.

It should be emphasised that there are more scientific studies that cover only some aspects examined by our study (defined by two or three keywords). A systematic literature review performed by Stuss et al. [26] using the keywords "CSR + Poland + Energy Sector" showed 32 publications in the ProQuest database in 2011–2021, in Emerald—10 publications, and in SCOPUS—4 publications. The search in the ProQuest database (August 2022) with the phrase "COVID-19 in Poland" leads to 321 records and "CSR in Poland" to 73. There is no article that summarises all the keywords in this work.

2. Corporate Social Responsibility (CSR) and Sustainable Development Concepts

There is no one specific definition of CSR [13]. Rather, the concept is defined by the context in which the term is used. CSR is a process in which business show their concern about the welfare of the environment and for people. The concept varies between society, and it is likely to change constantly according to the circumstances of each company [27]. The three pillars of CSR are: environment, society and economy [28]. In the International Organization for Standardization (ISO) conceptualisation, CSR is the method by which enterprises can adapt and manage economic, social and environmental issues for the benefit of communities, as well as measures in the field of social inclusion and human rights [29].

The reporting of corporate social responsibility (CSR) after the first years of chaos (especially now, due to appearing epidemic consequences), the so far widespread use of avoidance by companies or the presentation of facade solutions (stigmatised as part of greenwashing or latest warwashing) becomes increasingly honest and forward-looking, although still uncomplete. It is based both on voluntary commitments and actions by companies and on mandatory standards (in terms of transparency in reporting non-financial data) introduced by stock exchanges and state governments or institutions, such as the European Union. In fact, the documents prepared by the European Commission were of key importance for the development of CSR, especially:

1. Green Paper: Promoting a European framework for Corporate Social Responsibility (2001) [30];
2. White Paper: Communication from the Commission concerning CSR: A business contribution to Sustainable Development (2002) [31];
3. "A renewed EU strategy 2011-14 for Corporate Social Responsibility" (European Commission, 2011) [32].

The last document stresses that "that the economic crisis and its social consequences have to some extent damaged consumer confidence and levels of trust in business. They have focused public attention on the social and ethical performance of enterprises. By renewing efforts to promote CSR now, the Commission aims to create conditions favourable to sustainable growth, responsible business behaviour and durable employment generation in the medium and long term" (p. 2). These words about the financial crisis at the end of the first decade of the 21st century, began to come true unexpectedly a decade later in 2020s when the COVID-19 pandemic broke out, which changed economic activity in almost all parts of the world. It is this sudden change that we can call global, while the 2008 financial crisis had "only" an international dimension.

In the case of Poland, information about CSR practices by institutions is now available thanks to the Directive 2014/95/EU (relating to disclosure of non-financial information by companies) [33]. It was implemented into Polish law in January 2017. Furthermore, 2018 Polish companies are obliged to report on non-financial information in a free access [34]. However, despite the lack of obligation, the number of published non-financial reports continued to increase from one in 2005, with as much as a 50% increase compared to the previous year in 2010 (39 reports). Most non-financial reports in 2005–2016 were published (in order) by the fuel sector, banks, food and energy sectors [35].

In Poland, corporate social responsibility is a concept whose origins are seen in the economic practices of the country's companies in the 1990s. Although there were earlier publications about CSR in the field of economic activity (especially on the ethics of action), the dynamic diffusion of this idea took place only in the years 2006–2007 due to the massive influx of foreign investors to Poland [36]. However, already in 1999, the Council of Ministers adopted the document "Poland 2025-Long-term Sustainable Development Strategy" [37].

The first years of CSR in Poland are divided as follows [38,39]:

1. The first stage of CSR development in Poland (1989–1999)—phase of silence and lack of interest;
2. The second stage (2000–2002), CSR raised dislike and sometimes even opposition from many business leaders and economists, overwhelmed by the idea of "the invisible hand of the market" as a cure;
3. The third stage (2003–2004) brought interest in declaring recognition of ethics and social responsibility as a foundation of a company's conduct;
4. The fourth stage (2004–2005)—development of specific, albeit partial, projects,
5. involving certain significant areas of a company's functioning;
6. The fifth stage (2006–2007)—an attempt to link CSR with other strategies implemented in a company, i.e., communications, personnel, marketing or corporate governance strategy;
7. The sixth stage (2007–now) is of advanced implementation when managers of large and medium companies try to adapt their activities to standards seen in western practices.

Stakeholder expectations and a good image of the company, exchange of best practices, dissemination of CSR knowledge in the media and compliance with European requirements are factors influencing the development of CSR in Poland [40]. In the next segment, we will deal with the SDGs. These goals were set by the United Nations General Assembly in 2015 and included in the UN Agenda Resolution 2030 as a blueprint for the continuation of the Millennium Development Goals (MDGs). The SDGs are as follows [41]:

1. No poverty: End poverty in all its forms everywhere.
2. Zero hunger: End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
3. Good health and well-being: Ensure healthy lives and promote well-being for all at all ages.
4. Quality education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.
5. Gender equality: Achieve gender equality and empower all women and girls.
6. Clean water and sanitation: Ensure availability and sustainable management of water and sanitation for all.
7. Affordable and clean energy: Ensure access to affordable, reliable, sustainable and modern energy for all.
8. Decent work and economic growth: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.
9. Industry, Innovation and Infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation.
10. Reduced inequalities: Reduce inequality within and among countries.
11. Sustainable cities and communities: Make cities and human settlements inclusive, safe, resilient and sustainable.
12. Responsible consumption and production: Ensure sustainable consumption and production patterns.
13. Climate Action: Take urgent action to combat climate change and its impacts.
14. Life below water: Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
15. Life on land: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

16. Peace justice and strong institutions: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.
17. Partnership for the goals: Strengthen the means of implementation and revitalise the global partnership for sustainable development.

SDG7 is an objective directly related to the tasks of the energy sector. We can assume, that 8 out of 17 goals may relate also to this goal: (3) good health and well-being, (4) quality education, (8) decent work and economic growth, (9) industry, innovation and infrastructure, (11) sustainable cities and communities, (12) responsible consumption and production, (13) climate action and (17) partnerships for the goals.

Unfortunately, COVID-19 has slowed down the implementation of the increasingly efficient objectives of sustainable development. The World Bank points to "The 2022 edition of Tracking SDG 7" [42]: "The Energy Progress Report shows that the impacts of the pandemic, including lockdowns, disruptions to global supply chains, and diversion of fiscal resources to keep food and fuel prices affordable, have affected the pace of progress toward the Sustainable Development Goal (SDG 7) of ensuring access to affordable, reliable, sustainable and modern energy by 2030. Advances were impeded particularly in the most vulnerable countries and those already lagging in energy access. [...] The impact of the COVID-19 crisis on energy was compounded in the last few months by the Russian invasion of Ukraine, which has led to uncertainty in global oil and gas markets and has sent energy prices soaring". Since the authors in the previous work deplored the fall in fuel prices, which exacerbated economic and employment problems [14–16], it is necessary to highlight the extraordinary unpredictability of the energy market in recent years, not only due to the pandemic but also due to numerous political turbulence, without climate policy to forget.

Although much is said about sustainability issues, there is no theoretical or practical consensus about what CSR is and how it relates to sustainable development and business sustainability. However, international organisations believe that both CSR concepts and the SDGs are consciously and organisationally linked [9]. The Sustainable Development Goals are changing the debate on corporate social responsibility. The SDGs are the roadmap to a more sustainable future, and CSR is the first step. Companies have the necessary resources, manpower and technology to achieve the SDGs. The SDGs are much broader and more forward-looking than individual corporations, making the economy more social and sustainable [11,25]. CSR is also a key to promoting the SDGs [43].

CSR is popular in the energy sector. Companies promote renewable energy sources "and invest in improving their energy security and efficiency, updating their technology and procedures, and minimising the negative effects of energy storage and transport. Sustainable Energy Development (SED) (Sustainable energy development, recognized since 1987, is a complex multi-dimensional concept that can vary in meaning based on the context it is applied in and the perspective of the user [44].) goals aim to reduce pollution, increase efficiency, enhance alternative energy resources and utilize new technologies. In the meanwhile, energy supply sustainability is the guide to protect future needs while satisfying current requirements. CSR activities may lower the costs for consumers and encourage renewable energy and energy-saving technologies. [...] CSR elevates companies' non-financial performance such as carbon footprint mitigation" [25]. According to Tiep [45], the role of corporate social responsibility in achieving sustainable energy is positive.

Nair et al. [46] point out that the concepts of changing the role of SDGs after the pandemic suggest contradictory views in the literature. Some authors explain the growing importance of SDGs for the environment after COVID-19, while others discuss the possibility that COVID-19 may hinder the implementation of the SDGs. Authors "suggest that, in the new normal (post-pandemic), the SDGs within those principles ought to be re-prioritized and better integrated with CSR strategies and actions [...] and propose that corporate entities assume a more proactive role in reorienting their CSR initiatives to-wards achieving the SDG targets in the post-pandemic global context". The findings of ElAlfy et al. [15,47] "affirm the need to understand the environmental and social impacts of CSR activities on sustainable development and how current CSR performance can be improved and redirected to have long-term sustainable benefits on companies and society at large".

The flagship source of information on Poland's progress in the field of CSR and SDG are the reports by the Central Statistical Office [48,49]. "Poland on the path of sustainable development. Report 2020" was prepared on the 5th anniversary of signing the Agenda 2030 by Poland. The next 2021 Report was focused on selected threads of economic inclusiveness. Its leading topic was inclusive economic growth, emphasising the drop in regional and social inequalities since 2015.

Other information about CSR practices in Poland is available in numerous companies' reports [50], regional self-government [51], as well as nationwide [52]. Descriptions of good practices identified in local government competitions, including, in particular, the "Local Government Leader of Management" as part of the work of experience sharing groups and identified independently by the offices of local government organisations, by local government media and recommended by other local governments, were entered into regional self-government databases [51].

Apart from the above-mentioned databases, the most important source of information presenting CSR practices in Poland in the context of SDGs implementation is annual report "Responsible Business in Poland. Best practices" [53] published by the largest Polish NGO, named the Responsible Business Forum. The Forum is an expert organisation with the longest tradition in Poland, running since 2000, that initiates and partners in key activities for the Polish CSR. It presents the data in a comprehensive manner, dividing activities into seven areas, according to the ISO 26000 standard.

The report, which has been published since 2001, provides an overview of the activities of companies that have notified their CSR activities. Each year, it summarises the most critical issues of a responsible business in Poland, based on voluntary CSR reports from organisations (up to 10 practices per year per company can be submitted), and since 2016, it also includes information on good practices contributing to the achievement of the UN Sustainable Development Goal.

3. Materials and Methods

In order to obtain relevant information and maximally unbiased observations, a qualitative approach and individual interviews were chosen. To realise the objective of the study, the following measures were taken:

1. The research framework was defined.
2. In order to show the responsible and sustainable work of local authorities in implementing the strict policy of the next steps towards climate neutrality in the EU countries by 2050, data on good practices of local authorities were collected in the categories "Energy Efficiency" (the only category in the CSR database that directly addresses the energy dimension) and in two local initiatives (case studies for urban and rural areas).

The data are taken from the database of the nationwide local governments. It contains information on the energy practices of local administrative units. Its name is The Base of Good Practices, and it was launched in 2007 by nationwide self-government organisations. It collects descriptions of good and proven solutions in the field of improving the management of public services and the development of local government units, including institutional development, and since 2013, it also contains inter-government cooperation. At present, this database contains more than 500 standardised descriptions of practices, consistent with the adopted methodology. They are divided into several sections: Social services, technical services, institutional development, energy efficiency and others [52].

1. To demonstrate a similarly responsible approach by energy companies to the same ambitious goal of climate neutrality, the data were taken from the nationwide database

The Responsible Business Forum, which combines CSR practices with sustainability goals. Currently (data for the end of 2021), this database contains 7772 examples of good practices from Poland, 783 companies involved in CSR, 28 industries and 20 reports of Good Practice [54]. This is a record growth in reported practices over the year (by 1664 examples), and it is still the epidemic period (but with less restrictions and mass vaccinations against COVID-19). The companies engaged a report on a maximum of 10 best practices. Qualifying a good practice requires its compliance with the concept of corporate social responsibility. The final evaluation is carried out by the qualifying committee, which includes representatives of the Responsible Business Forum. The data collected allow us to link the good CSR practices with Goal 7: affordable and clean energy, which is of interest to us in this case. The analysis of changes in CSR practices in the energy sector during the COVID-19 epidemic was based on data from the following years:

- since 2016 but before the epidemic outbreak (that is, since both categories: CSR and SDG appear in the reports)
- and in the first epidemic year 2020 (before vaccination against COVID-19) as well as in the second year 2021 (with vaccination against COVID-19).

2. In order to assess the companies' understanding of the CSR objectives and the degree of implementation of the measures (usually not only in the energy sector), the results of a sample of more than 400 companies from the Lublin district in south-eastern Poland were presented. A preliminary questionnaire was introduced in 2018 and updated in 2021.

A descriptive qualitative analysis was used to answer the research questions. This method makes it possible to collect and combine systematic, objective, and repeatable research information. The empirical basis of the study is the cross-sectional time series contained in the annual reports. These databases have a good reputation and are used in several domestic [55,56] and foreign [57–60] publications, including some published in *Energies* [26,61–63].

With such vague concepts as CSR and the implementation of SDG, the use of statistical analysis is not justified. "Numbers are not inherently superior to sound judgments" [64]. It should be noted that all subjective data provided by companies are available online in free access. Companies are prepared to publish information on their best practices in order to disseminate them while strengthening the company's image [65]. When actions are reported not as a whole but as several separate tasks, which statistically increases the number of remarkable achievements, it can be an advantage of the prepared databases, as well as its disadvantage. Such an assumption discourages the use of statistical methods all the more.

4. Results

In answer to **research question 1**: To what extent are local authorities involved in the implementation of CSR good practices in the field of energy efficiency? In Sections 4.1 and 4.2, we focus on CSR initiatives that are voluntarily submitted by local authorities to the nationwide Good Practice Database [52]. This section discusses the initiatives taken but also highlights two examples of such activities, one in the urban areas and one in the rural areas.

To answer **research question 2**: To what extent does the energy sector contribute to the implementation of CSR good practices for "access to affordable, reliable, sustainable and modern energy" (SDG 7)? We used data extracted from the database Responsible Business Forum [54]. We were looking for data sets that met the following requirements: thematic area (multiple according to CSR dimensions1), industry (we chose the Energy sector), source of good practice (reports 2016–2021), selected from the Sustainable Development Goal (SDG7) list.

The next step was to search the records by the name of the organisation (company) and the following years (by entering the report for the corresponding year in the source of good practice window). The results are presented in Section 4.3.

This section also contains the information required to answer **question 3**: Has the COVID-19 outbreak reduced the involvement of energy companies in the implementation of SDG7? All data for answers to question 2 and 3 are arranged by years, i.e., before the pandemic (2016–2019) and during the pandemic (2020–2021).

Section 4.4 presents the results of the survey in response to **research question 4**: Do entrepreneurs (regardless of the sector) understand the concept of corporate social responsibility?—using the example of local companies from the Lublin district.

4.1. Energy Efficiency in a Common Base of Good Practices of Local Government Units

Data on good practices used here are provided by the energy efficiency section up to the end of May 2022. The "Energy Efficiency" category has significantly less good practice than the "Social Services", "Technical Services" and "Institutional Development of CSR" categories. In the energy efficiency category, 41 practices were registered, of which 4 were in rural communes, 7 were at subdistrict (poviat) level and 30 were in urban communes (the most in Bielsko-Biała, Częstochowa and Poznań, respectively) [52].

The activities in rural communities included:

- Comprehensive activities increasing energy efficiency, improving the ecological effect based on investments using **renewable energy** sources in Gierałtowice;
- An initiative to increase the use of **renewable energy** sources (Kobylnica);
- Comprehensive use of **renewable energy** sources as one of the pillars of the sustainable development of the rural commune of Słupsk;
- Reduction in pollutant emissions using **renewable energy** sources in a rural Mazurian commune (Stare Juchy).

At the subdistrict (poviat) level, in fact, most of the "city" problems were implemented, such as:

- Center for **Renewable Energy** Sources in Bielawa;
- Comprehensive program of atmospheric air protection in the scope of limiting the emission of pollutants into the atmosphere of the city of Bielsko-Biała from residential buildings;
- Improving air quality and increasing the use of **renewable energy** sources by modernising the heat source and installing solar collectors for SPZOZ County Hospital in Bochnia;
- Optimisation of energy and environmental management in public buildings of the city of Częstochowa;
- Cooperation of the poviat self-government with non-governmental organisations in the effective use of **renewable energy** sources in the nursing home for children "Rainbow House" in Ełk;
- **Renewable energy** sources as the basis for the modernisation of the school heating system;
- Comprehensive modernisation of thermal energy installations based on **renewable energy** sources in the nursing home.

In addition, many varieties of the city energy programs were reported directly at city level as one of the pillars of effective city management, solar roofs, changes in street lighting, educational programs, etc:

The activities in city communities included (location and name of the project):

Northern Poland:

Dzierzgoń (33 th. inh.)—**Sunny roofs** for the Dzierzgoń commune.

Dzierżoniów–Energy management in a small town—a model proposal

Kępice (69 th. inh.)—Cooperation of the municipal government with the state forests and other entities in the use of **renewable energy sources**.

Central Poland:

Głowno (14,5 th. inh.)—Modernisation of street lighting in the city of Głowno.

Płońsk (22,55 th. inh)–Modernisation of the district heating system of the city of Płońsk.

Poddębice (7,5 th. inh.)—CITY OF THE SUN—the use of **renewable energy** sources for heating purposes in the strategic promotion of the Poddębice commune.

Uniejów (3 th. inh.)—The only **geothermal heating system** in Poland without the use of conventional heat sources as a supporting system.

Western Poland:

Gniezno (69 th. inh.)—Gniezno Poviat—Biofuels.

Poznań (540 th. inh.)—The use of biogas from municipal waste for combined energy production as an element of comprehensive waste management in the Poznań agglomeration.

Poznań—"Keep warm" 2010/2011—a program for **free thermal imaging** of buildings.

Poznań—EcoDriving of safe Poznań—the local government promotes driver education, serving the safety of city traffic and environmental protection.

Eastern Poland:

Ełk (61,5 th. inh.)—Investments in **renewable energy** sources as an element of the integrated eco-development policy of the city—"Renewable Energy Master".

Ełk—CITY ENERGY PROGRAM as one of the pillars of effective city management.

South Poland:

Bielawa (30 th. inh.)—Environmental education in Bielawa from kindergarten to university.

Bielsko Biała (530 th. inh.)—Educational and promotional campaign "Bielsko-Biała protects the climate."

Bielsko-Biała—Energy management system in Bielsko-Biała.

Bielsko-Biała—**Renewable Energy Sources** (RES)—an innovative concept for training future staff in Bielsko-Biała.

Bielsko-Biała—Monitoring of the energy market in Bielsko-Biała.

Bielsko-Biała—Low emission reduction program in Podbeskidzie—a successful example of replicating the experiences of the Tychy local government in Bielsko-Biała.

Częstochowa (225 th. inh.)—A tender for the purchase of electricity is one of the elements of cost optimisation for local governments.

Częstochowa—Council for Sustainable Development of the Energy Economy of the City of Częstochowa as a platform for cooperation between entities shaping and implementing the local energy policy.

Częstochowa—City of Sustainable Energy—Częstochowa local government is the promoter of the exemplary local energy efficiency action plan.

Częstochowa—Energy and environmental management in public buildings of the City of Częstochowa.

Radlin (17,8 th. inh.)—The use of **solar collectors** (RES) as part of the modernisation programs of heat sources implemented by the commune.

Radlin—Low Emission Reduction Program.

Kluczbork (24 th. inh.)—Cooperation of the municipalities of Opole Silesia in effective energy management on the example of the negotiation process with an energy concern.

Kraków (768 th. inh.)—Comprehensive action of the Municipality of Kraków for energy efficiency.

Nowa Dęba (11 th. inh.)—Effective use of biomass energy in combination with sewage waste for ecological city heating.

Świdnica (57 th. inh.), Lubin (71 th. inh.)—Reduction in electricity purchase costs through cooperation of local governments within the purchasing group.

Tychy (127 th. inh.)—Effective and **environmentally friendly heat sources**—the Tychy program for reducing low emissions (PONE).

To sum up, the basic objectives for renewable energy provision are included in all good practices reported by rural authorities, almost all by subdistrict (poviat) authorities and only in some cities. Good practices for cities (Bielsko-Biała, Czestochowa, Poznań, Dzierżoniow, Ełk, Radlin) were submitted extensively and some cities have reported several (sometimes they are related, such as the reported practices in the energy dimension in Częstochowa city). Most cities participating in the CSR good practices in energy efficiency are small towns (up to 70,000 inhabitants), mainly in the south of Poland. From cities with more than half a million inhabitants, only initiatives from Krakow and Poznan are reported. Unexpectedly, Warsaw (capital) and the three-city (Gdańsk-Gdynia-Sopot) are missing. In each of the five zones of Poland (North, West, East, Central and South), there are renewable energy supply initiatives, but the number of notifications is low. Best practice reports from southern Poland focus on the modernisation of heating systems. These are areas with high air pollution in the country [66], and the municipalities are striving to reduce low emissions (smog). Since 2022, the oldest solid fuel boilers have been banned in two districts of southern Poland (Silesia and the Subcarpathian). Both resolutions concern boilers in service more than 10 years after their manufacture and boilers without a nameplate. From 2023, the oldest boilers in the capital region and in south-eastern Poland will also be banned [67]

4.2. CSR Local Practices in the Energy Sector–Case Illustration

4.2.1. Township Scale

The example chosen to illustrate measures to implement the Sustainable Development Goals correlated with CSR relates to a project to modernise street lighting in the town of Głowno in central Poland. It is a small town with about 5000 inhabitants. Until the modernisation project, more than 1500 light points were installed in the urban area, most of them mercury lamps. The old lighting system had an output of 280 kW. Mercury lamps produced copious amounts of hazardous waste and were less efficient. The aim of the modernisation was to illuminate streets and public spaces in compliance with current standards while reducing the so far installed capacity. After replacing the lighting, the total installed capacity dropped to about 155 kW. The estimated cost of the luminaires to be replaced was about 500 thousand PLN (around 106 thousand euro). The financial effects show the difference in the cost to the city budget in the winter months before and after the modernisation of the system, which decreased by more than 30%. Account should be also taken of the shadow prices associated with mercury-containing waste, which is no longer present in the system. Other benefits have to do with improved social security, as the lighting system is now more efficient. The project started before the epidemic and was completed in 2020–2021 [52].

4.2.2. The Case of City Rural Surroundings

This is the case of the rural surroundings of Słupsk city located at the Baltic Sea. This area is known for its project to install the American missile shield, but here, the main point of our interest is its very intensive local government's environmental policy. Through a dynamic investment policy for the efficient use of renewable energy sources, the small municipality is one of the leaders in the use of renewable energy, not only in rural communities but also in many much larger and more prosperous municipalities. In this context, a gradual thermo-modernisation of the buildings has been carried out since 2001, and in 2004, the modernisation of school boilers was completed, leading to the commissioning of five independent biomass boilers. In 2005, own energy pasture plantations were set up for the heating cellar, and two years later, the municipal biomass heating plant was established. In 2009, the municipality implemented the "Solar Installations in the Municipality of Słupsk" program under which individuals and small businesses could apply for a partial grant for the purchase and installation of solar collectors. The collectors were also installed in the buildings of the municipal water park in Redzikovo. In the same year, a street lighting system with LED lamps and solar panels was installed. All these measures led to significant savings in electricity consumption and a significant reduction in air pollution in the municipality. As a result, the inhabitants of nearby Slupsk city prefer to move to the area of the village Słupsk and increase their budget by increasing tax revenues. The brand "I fly for the city" promoted in this way has become the calling card of this corner of Poland [52].

4.3. CSR Practices in the Energy Industry in Conjunction with the Sustainable Development Goals

Good CSR practices in the Energy sector were reported 63 times in total in the analysed years 2016–2021, including 19 in 2021 and 14 in 2020, which means 33 in both years of the epidemic (2020–2021) (Table 1).

Table 1. CSR good practices in the energy sector in Poland in a framework SDG 7 by core subjects of ISO 26000 (in 2016–2021).

7 Core Subjects of ISO 26000	2021	2020	2019	2016–2021	CSR Activities by Type 2016–2021
Organisational governance	1	0	0	1	Management (1)
Human rights	0	0	0	0	
Labour practices	0	0	0	0	
Environment	16	10	4	40	Certification (2) Ecological education (6) Eco-office (1) Eco-construction (2) Eco-efficiency (13) Eco-products (2) Circular economy (2) Renewable energy sources (8) Pro-environmental programs (3) Sustainable transport (1)
Fair operating practices	1	3	0	5	Market education (3) Relationships with suppliers (1) Relationships with stakeholders (1)
Consumer issues	0	1	0	13	Availability of products and services (2) Consumer education (8) Facilitation for customers (3)
Community Involvement and development	**1**	0	1	4	Good neighbour (1) Charity and philanthropic activities (0) Education of children and youth (2) Sustainable cities (1)
TOTAL	19	14	5	63	20 types

Source: own selection [54].

This means that most good practices were reported in epidemic years, and by far the most in 2021, when anyone wanting to vaccinate against COVID-19 was able to do so because a number of vaccines were available. As a result, the year 2021 was not dominated by charities for medical infrastructure, as was the case in the first year of the 2020 pandemic. However, it should be noted that most deaths in Poland occurred in 2021 (15 April), and then on 1 January 2022 [20]. It is, therefore, difficult to say whether conditions in Poland were safe enough to forget about the pandemic and focus on different CSR activities and the achievement of SD goals outside of health. Without the pandemic, the interest of the energy sector in achieving the European Union's "Fit for 55" targets probably could increase. In the years of the 2020–2021 pandemic, the energy sector reported 22 charitable and philanthropic practices, including 17 in the first year of the 2020 pandemic. Only one non-profit project listed in Table (Table 1) means that only that project was notified for the achievement of SDG7. In total, the energy sector reported 44 best practices under philanthropy over the period 2016–2021, which shows that the energy sector increased its philanthropic activities in the field of charity and philanthropy in 2020, compared to other years [54].

However, when assessing the level of interest of the energy sector in the implementation of the environmental policy prepared and subsequently adopted by Poland, the interest was relatively low compared to expectations and overall objectives. In 2016–2021, 194 good practices from all sectors listed in the database were reported (including 30 under the renewable energy category) to implement SDG 7 (affordable and clean energy). However, it represents only 2.5% of the total number of good practices included in the database in those years. Only one third of the 2.5% was proposed by energy companies. In addition, the practices reported by energy companies (usually large and state-owned), were more than 12.5% (63 out of 504 reported), and thus, the proportion of these practices among energy companies was higher than in other sectors of the national economy. Which should not be surprising.

In the epidemic years 2020–2021, energy companies returned 16% of the reported SDG 7 good practices. Before the pandemic, 2016–2019, it was only 10%, and if one looks at just one year before the pandemic, it is even less than 7% of all reported good practices (affordable and clean energy). Therefore, it can be assumed that the outbreak of the epidemic and achievement of other objectives by companies, such as philanthropic or public health objectives [8], did not change (or stop) the achievement of SDG7 in their routine activities. This can probably be explained by the low level of commitment on the part of companies that are predisposed to these activities. If so, we have to ask why?

Some of the companies running in the energy market and reporting CSR practices did not have activities related to the provision of affordable and clean energy at all. For example:

- **Veolia Energia Polska**, which notified four practices (SDG 4 and 11), but none in the energy sector;
- **Poland Energy**, 14 practices, none related to SDG 7;
- **Tauron Poland Energy**, 62 practices (20 in 2020–2021), of which only 9 are linked to SDG 7, while 21 are linked to SDG 3 (health and quality of life improvement), and 20 are linked to SDG 4—good education. In the pandemic years 2020–2021, Tauron carried out such practices as: Video cabin with an advisor, Feel the magic of Christmas, Don’t lose shape, Train at home!, Plant Experimental Area, Great Joy on Two Wheels, MegaPower of Christmas Carols, etc. The few that relate to SDG7 and renewable energies are: new sources in the “TAURON virtual power plant”, Take no smog, Take a breath, EKO Premium product, Electricity and heat from methane, Photovoltaic farm on the site of a former coal-fired power plant, eco-competition “Subsidy for the house”;
- **PGNiG**, 32 practices (18 in pandemic years, 10 in 2020 and 8 in 2021). Only 4 practices were related to SDG 7 (of which 3 were in 2020): RIPEE—Register of Energy Efficiency Initiatives, Energy from the Sun, ISO 50 001 certified—Energy Management System, PGNiG Thanksgiving Account;
- **PKP Energetyka**, 16 practices, including one linked to the achievement of SDG 7: Traction energy storage system PKP Energetyka;
- **ENEA**, 62 good practices, including 6 related to SDG7 in the areas of consumers’, children and young people education; there is no connection to renewable energy sources;
- **PKN Orlen**, 60 practices, including one in the eco-efficiency category under SDG 7 Investment projects with innovation, innovation and R&D components of the 2021 Decarbonisation Programme;
- **Energa ORLEN Group**, 29 practices, including 6 related to SDG7, in the category of sustainable cities, eco-efficiency, environmental programmes, consumer education, certification; no connection to renewable energy sources;
- **Veolia Group**, 32 practices, but only 6 related to SDG7: Innovative Energy Installation—Heat Recovery from Waste Water (Szlachęcin), Energy Efficiency of Buildings—Competition at Veolia Group in Poland, Transformation2050. pl, Veolia Group’s Intelligent Heat Network in Poland and two in the Circular Economy category: Ob-

taining heat production from industrial processes for district heating and the use of waste gas for heat generation;

- **Polsat Plus Group** (Cyfrowy Polsat, TV Polsat), 22 good practices, 2 of which are related to SDG7, including 1 on renewable energy: the Polsat Plus Group on Green Energy from the Sun;
- **Columbus Energy**, 9 Best Practices (all from 2021), of which 3 are related to SDG 7, in the categories "eco-products", "eco-office" and "environmental education".

In 2016–2021, only 6 good practices met SDG7 exclusively, in the categories of consumer education, market education or children and young people education (mainly in 2016). In other cases, several SDGs (two to five) were achieved simultaneously and within the same project. In these cases, SDG7 was in first place only four times. The most frequent combinations with SDG 9: industry, innovation and infrastructure (27 times) and SDG 13: climate action (27 times) as well as SDG11: sustainable cities and communities (19 times) and SDG12: responsible consumption and production (18 times). In addition, it was combined with SDG 4 (7 times), SDG 8 (2 times) and once with SDG 14, 15 and 17.

4.4. The Problem of Understanding CSR and Raising Awareness of Sustainable Development Goals among Companies' Leaders

The problem of understanding CSR and raising awareness of the Sustainable Development Goals is of particular concern to companies. The same was noticed in the Stawicka and Paliszkiewicz paper based on a statistical database [65]. Grass root level research shows this question in detail. A survey of the local economic activity in the Lublin district made in 2018–2020 included the sample of 448 companies. Students from the University of Economics and Innovation in Lublin, who are members of the Student Scientific Circle, took part as interviewers. They approached this task very responsibly by adding information from the supplementary interviews to the printed questionnaires. The students live in different localities of the Lublin district, so the geographical scope of the research was broad and involved companies of varied sizes and activities. Out of a total of 448 surveys, 162 were conducted in Lublin city, 103 in other major towns of the district (Zamość, Chełm, Puławy, Kraśnik) and 183 in smaller settlements. The various locations of the companies were an additional factor taken into account in the analysis [68].

The objective was to assess the extent to which entrepreneurs in local markets understand the challenges of CSR implementation and whether CSR practices improve competitiveness. The project covered several aspects of corporate social responsibility. The first question was whether the operators were aware of the CSR and then whether they applied measures in favour of the CSR. It was only then that the qualitative question arose of what a company implements in this area, how it does it and what impact it has. For formal reasons and in order not to discourage respondents unnecessarily, the benchmark for gender, age, education, etc. used in research was omitted.

The questionnaire included five questions, namely:

1. Are you familiar with the concept of corporate social responsibility?
2. How can this concept be defined?
3. What activities do you associate with corporate social responsibility?
    a. Charitable purposes (social assistance)
    b. Emergency assistance
    c. Protection of the environment
    d. Other?
4. Does your company meet the objectives of CSR in the above-mentioned area? How?
5. What are the benefits for your company of implementing CSR?

The starting point of the discussion on the application of CSR principles at the local level was the entrepreneur's approach to the concept. Question 1 "Are you familiar with the concept of corporate social responsibility?"; approximately two thirds of respondents answered yes. Is it a high percentage? Apparently no, which was also confirmed by the answers to the following questions in the survey, which means that the idea of CSR needs to be popularised. There were fewer respondents, as only about 50% of respondents from Lublin city and the larger cities in the region reported using CSR (question 4) and even fewer (42%) in small towns and rural areas. Therefore, there were hardly any differences in the responses according to the location of the company. These results cannot, of course, be regarded as highly representative, but the quantitative survey suggests a trend even if the companies are randomly selected. Incidentally, it should be noted that corporate social responsibility was earlier promoted in Lublin city under the Swiss–Polish Cooperation Program, although this action concerned recycling.

Qualitative research leads to more interesting conclusions. There were several. In the beginning, it was an intellectual task to define the concept of CSR (question 2). It was shown that fewer people are able to deal with this issue than those familiar with the term "CSR", although these figures roughly corresponded to the number of companies applying CSR principles (see the Table 2). The review, therefore, confirms that local entrepreneurs are generally unaware of CSR.

Table 2. CSR knowledge, ability to define and apply (% of respondents).

Location	Knowledge of CSR (%)	Ability to Define (%)	Applying CSR (%)
Lublin city	69	43	46
Towns	62	52	56
Other settlements	66	38	42
Total number of respondents		448	

Source: [58].

This project has shown that there is still little awareness of CSR objectives at the company level. The majority of respondents saw CSR as support for the people in need but felt that this should be provided by the state and NGOs. For some respondents, CSR is associated with charity, especially in crisis situations, and with the involvement of the company's employees in solving problems in the local community and in solving problems related to workers' rights. Unfortunately, the topic of sustainability was secondary in the interviews (recycling, energy saving). The results show that education needs to be fully supported if CSR is to become ubiquitous and even mandatory.

5. Discussion

Renewable energy plays a strategic role in the decarbonisation process to combat climate change, as it plays an increasingly important role in electricity markets. When assessing what Poland has achieved in order to provide affordable and accessible clean energy for all, it should be noted that the changes that need to take place in the Polish economy are incomparably greater than in other EU countries. Achieving these objectives requires not only substantial financial resources but also responsible decisions, because changes affect many citizens (especially coal workers), as well, six regions are linked to coal. It is estimated that, by 2030, approximately PLN 300 billion could be made available for national transformation and approximately PLN 60 billion for coal conversion. EU funds, from the Just Transition Fund, Cohesion Policy, and the Facility for Reconstruction and Resilience, can play an important role. National funds are also to be involved, and a special role in this area is already played by programs implemented by the National Fund for Environmental Protection and Water Management and district funds, the Modernization Fund and the Energy Transformation Fund [2].

We are currently in a difficult time in which we have to counteract both the risks of negative climate change (long-term objective) and the protection of citizens' health (short-term objective COVID-19 goal). Although we know little about the post-pandemic period, this will certainly be a shorter episode in world history than the reversal of the negative climate change we are already witnessing. However, with the rapidly increasing number of illnesses and deaths, it is difficult to imagine that we would wait (at individual and company level) without doing anything but calmly pursuing our statutory goals. Therefore, the involvement of energy companies in the activities during the COVID-19 pandemic, particularly in the field of material aid to hospitals, local communities or philanthropic activities, was very clear [8,69]. However, it must be emphasised that policies to promote affordable and clean energy (SDG 7) do not differ significantly before and during the pandemic.

Perhaps it is because this is still a margin of activity for companies whose main task is to supply energy. Another reason is the different approach (lack of standardisation) of Polish energy companies to the implementation of good CSR practices, unless they refrain from reporting on good practices, even though they are being applied by them. However, studies carried out by Stuss et al. on the example of the largest Polish energy companies with international status show that there is a standard approach to CSR in all Polish energy companies. The three largest energy companies (Enea Group, Tauron and PGE) assessed that the way they build their CSR strategies is based on: formalised CSR concept, published CSR reports, disclosure of CSR information on the company's website, CSR activities for stakeholders, content of CSR certificates and CSR awards [26].

The question arises as to why affordable and clean energy (SDG 7) stands for only a small proportion of CSR activities of energy companies (10–12%) as an objective of good practice. To demonstrate good CSR practices, they combine SDG7 with different objectives. Why? Is it just a marketing measure? To answer this question, it is worth looking deeper. However, it seems that: CSR "concept is still understood by many as sponsorship and philanthropy. The main barriers to CSR development in Poland include lack of qualified staff, inability to see the direct effects for business, poor incentives from the state administration, insufficient time, and limited financial resources" [2,36]. Tylec's study [40] shows that the exchange of good practices, the expectations of stakeholders (in line with the expected image effects) and the dissemination of CSR through the media are the three most important factors for the development of CSR engagement in Poland, bearing in mind the need to follow Directive 2014/95/EU [34]. The factors hampering the development of CSR in Poland are repeated statements in another study that it is a lack of knowledge and funding [40]. Based on the surveys carried out in the Lublin district, we believe that the lack of knowledge and capital is the main obstacle to the development of CSR in Poland for small and medium-sized enterprises. Similar to Witek-Crabb [38], we do not believe that large publicly owned listed companies (and most of those who enter good practices in the energy sector into the Responsible Business database) have a problem with lack of knowledge [70], perhaps with a lack of capital, which is worth checking in future studies. Tylec's study [40], pp. 269–270, based on surveys among entrepreneurs in the period 2016–2020 reporting good practices to the Responsible Business Database (the same used in this study), shows that "some entrepreneurs/managers are aware of the importance of socially responsible activities, their impact on business performance and their impact on business performance integrates them into management strategies. At the same time, there are companies and managers who come closer to Milton Friedman's statement that the company is primarily responsible for achieving economic objectives. Contrary to literature studies, the surveys (which target a selected group of entrepreneurs) in Poland do not confirm that CSR is generally recognised as a concept of governance, is strategically important or has been given even more prominence in recent years". It is important that in 2020, only 4% of respondents believed the company benefitted from CSR, compared to 17% in 2018. The lack of a budget for socially responsible measures was confirmed by 8% of respondents in 2017, 21% in 2019 and 11% in 2020. At the same time, 40% of respondents were unable to estimate the value of the CSR budget [40], pp. 268–269. Has the pandemic affected the financial problems of non-financial bravery? In view of the existing ambiguities, the investigations should be continued.

Regarding the impact of CSR on a company's finances, there is an interesting work by Chodnicka-Jaworska [71] that is based on data from 9521 European companies and examines the impact of ESG (environmental, social and corporate governance (ESG)) on corporate returns during the COVID-19 pandemic. It was shown that prior to the outbreak of the pandemic, more attention was paid to ESG factors, and during this crisis, investors often viewed investing in ESG as being at risk of losing money. In the subsectors, the factors from groups E and S showed the greatest significance. At the same time "sectors react differently to ESG scores. The most sensitive are the energy, industrial (on social responsibility), materials, and utility sectors. This is strictly connected to regulations related to pollution reduction as well as energy and water conservation" [19,71]. Boldeanu et al. [72] demonstrated, that the pandemic had a significant negative impact on European electricity companies (in terms of abnormal returns) but the impact was more pronounced for renewable electricity companies than for traditional ones. However, contrary to the results of Chodnicka-Jaworska [73], which confirmed the impact of ESG measures on energy sector credit ratings and confirmed a significant impact of ESG on energy sector credit ratings during COVID-19, these authors obtained different results. After the World Health Organization (WHO) declared COVID-19 a global pandemic on March 11, 2020, they investigated which pillars influence the company's performance. They also showed that it is consistent with the current literature, which states that ESG factors were irrelevant during the pandemic on stock returns. This relationship is, therefore, to be regarded as unclear and requires further investigation and the application of different assessment methods, from quantitative to qualitative.

Particularly "in the case of the Polish energy sector, the expectations that the declaration of compliance with CSR rules will translate into an improvement in the level and stability of profitability and stock market quotations of companies are not confirmed. In the case of this sector, changes in the strategic conditions of its functioning play a more important role than social responsibility" [19,74]. These may be factors influencing the decisions of large energy companies to reduce their participation in CSR good practices. Although the number of initiatives proposed is no fewer or even greater than before the epidemic (chapter 3), the financial cost and commitment of employees is not in line with the fundamental changes expected in the European decarbonisation policy.

Codogni [75] distinguished four levels of commitment, attitudes of enterprises, and issues related to corporate social responsibility, with Polish participation in types 2 and 3:

1. Obstructionism—enterprises do as little as possible to solve ecological and social problems.
2. Defensive attitude—the organisation respects only the applicable law but otherwise does nothing for the local community or the natural environment.
3. Adjustment attitude—regarding CSR, the organisation fulfils its basic legal and ethical duties and, in some cases, goes beyond those duties.
4. Active attitude—the organisation perceives itself as a citizen and actively seeks ways to contribute to the social good.

Witek-Crabb [38], based on the analysis of the content of the website, carried out a comprehensive diagnosis of the CSR maturity of Polish companies based on the conceptual model of CSR maturity, which consists of three perspectives: process maturity of CSR, formal maturity of CSR and development maturity of CSR. Between 2016 and 2017, the CSR practices of 93 listed companies from nine industries were analysed. The main finding was that the CSR practices of Poland are still quite low: 47% of companies implement incidental CSR, 30% tactical CSR and 23% apply strategic CSR. She found that the CSR maturity level is company-size- and industry-dependent. "The most mature CSR practices in the studied sample were implemented by the banking and energy sector companies. Average results of companies in these industries place them on or close to the strategic level. [. . .] In these enterprises, CSR is a part of the business strategy and daily operations. CSR activities are planned, and their results are monitored and measured" [18,38].

However, it should be emphasised that in the field of environmental CSR in Poland, there was more intensive activity than the database of good practices suggests. Studies based on annual reports of leading oil, gas and mining companies (PKN ORLEN, PGNiG-Polskie Górnictwo Naftowe i Gazowe and KGHM Polska Miedz) show their strong commitment to environmental CSR: environmentally friendly initiatives and projects. areas for the environmental protection were as follows [76]:

- application of environmentally friendly technologies and techniques to reduce the negative environmental footprint;
- reducing the emissions of greenhouse gases (decarbonisation);
- regularly monitoring and reporting the outcomes of the environmental activities,
- including the use of natural resources, the level of emissions and waste;
- aiming at the achievement of the maximal ecological neutrality, including the use of water;
- increasing the involvement in the area of the closed circle economy, the development of distributing infrastructure for alternative fuels (e.g., electrical energy, bio-fuels and hydrogen);
- conducting and participation in R&D projects in terms of new technologies;
- identification and fulfilment of legal requirements and other regulations, undertaking remediation and reclamation measures.

It seems that these are main activities aimed at eliminating or minimising the negative impact of the company’s activities on the natural environment. Initiatives to change the company’s strategy for affordable and clean energy play only a minor role at present.

The strategic challenge for Poland (as mentioned before) is to abandon coal as an energy source and replace it with renewable energy sources, nuclear energy, hydrogen, etc. These first—renewable energy sources—now account for almost a third of the total installed capacity of all energy sources. Currently, the sun is the largest renewable energy source in Poland [77]. Photovoltaics are the most popular on a smaller, even individual scale, such as in households, schools, nursing homes, medical clinics, which significantly affects the dispersion of energy sources in Poland. This preference is reflected in the analysis of the local initiatives taken (Sections 4.1 and 4.2). Essentially, local energy independence will reduce energy costs and ease of access.

This is beneficial not only because of the need for renewable energy but also for unforeseen phenomena such as epidemics (with disruption of the supply chain) or impending political conflicts [78].

The main obstacles to the development of renewable energy are limited opportunities for companies to finance investments, legal support schemes, administrative and procedural difficulties and problems in the operation of transmission networks. In some cases, the current regulation hampers the development of renewable energy sources, as evidenced by wind energy. Wind energy can become a leading renewable energy source in the short term and provide more energy than photovoltaics. However, the obstacle is the so-called distance law, which affects the development of new wind farms. This is a consequence of the application of the “10H” rule, i.e., the possibility of setting up wind turbines at a distance of at least 10 times the height of the power plant at maximum rotor height. It is easy to calculate that with a wind turbine of 150 m, the minimum distance from residential buildings is 1500 m. This barrier will be removed by an amendment to the law that provides for a minimum distance between the windmill and the buildings of only 500 m.

Another important requirement for increasing the share of renewable energy sources is cable pooling, i.e., the possibility to share the energy infrastructure between different generation sources, e.g., integrating photovoltaics to a wind farm. Additionally, the idea of industry with its own renewable energy sources, without the transmission grids (which in Poland are congested and need to be modernised) is also examined. This would eliminate state intermediaries, which in practice, leads to lower costs for industry [78].

6. Conclusions

The authors have focused on the energy sector, represented in Poland mainly by large companies with state capital listed on the Warsaw Stock Exchange. The companies face the far-reaching goals to change the energy profile of Poland into a more pro-environmental one, moving away from coal towards clean, easily accessible and, ultimately, cheaper energy sources. These targets are set for all EU countries for the coming years and decades, as Europe is the first continent in the world to have declared itself climate neutral by 2050. The transition to a climate-neutral economy is both an urgent challenge and an opportunity to ensure a better future for all. In this context, it became necessary to analyse the progress made by the Polish energy sector towards achieving the Sustainable Development Goals 7, i.e., securing energy through the application of good business practices. As the plans may have changed or slowed down due to the urgent risks of the COVID-19 pandemic, supplementing the analysis with a more detailed analysis of the situation over the period 2020–2021 has led to cautious conclusions.

In answering the first research question, we found that the number of good local practices reported is very low. As of 1 January 2022, the administrative structure of Poland consisted of 16 districts, 314 counties and 66 county-level towns, 2477 municipalities (including 302 urban municipalities, 662 urban–rural municipalities and 1513 rural municipalities) [79]. The fact that only 41 good practices were reported is a symbol of this state of matters. This means that municipalities do not have such plans or do not report such practices. The information obtained from databases allows us, on the one hand, to monitor the activity of energy companies on their territory. It is interesting to see whether the wishes of local authorities are in any way compatible with the sustainable and responsible management of energy companies. After compiling the data from the two databases [52,54], it seems that there is a discrepancy between the plans of local governments and large energy companies. Local government officials plan infrastructural investments in renewable energy sources or energy efficiency, as they serve the residents of the administrative unit. The aim of energy companies is to improve the image of the company or, more generally, to fulfil the task of adapting the country to international climate policy. Although these goals can be achieved, they rarely are. CSR activities are more closely correlated with public relation, as other authors have already mentioned [80].

In the search for an answer to the second research question, we have noted the important philanthropic activity of energy companies, but unfortunately, many good practices in the field of clean and accessible renewable energy are not impressive and insufficient to meet the objectives of EU climate policy. Despite the increasing number of reports and good practices reported, the phenomenon is unsatisfactory.

However, the impact of the pandemic on the implementation of Sustainable Development Goals 7 in the area of CSR is not a hindrance. It is even possible to speak of some intensification of efforts to close this gap during the pandemic. Combining SDG7 with many other SD targets in a project, however, implies an image rather than an actual activity. Or, according to the results of the attempt to answer the fourth research question, the entrepreneur does not have the knowledge to integrate himself into the concept of corporate social responsibility. This is also confirmed by the literature. A certain facilitation is the dependence of CSR in Poland on the European Union guidelines and legislative solutions. Moreover, Tylec's study [35] shows that the least barrier to the implementation of socially responsible business (and of constantly decreasing importance) is legal regulations.

Hypotheses 1, 2 and 4 were confirmed in the work. The hypothesis 3, stating that the role of the epidemic in the work on the responsible approach to the implementation of SDG 7 in Poland, remains unconfirmed.

The current COVID-19 pandemic still is in progress and continues despite the government replacing the epidemic in Poland on 1 April 2022 with an epidemic emergency. The consequences cannot be predicted reliably. In the case of the Polish energy sector, however, the impact of the epidemic was overshadowed by other events, the most important of which was the outbreak of the war in Ukraine. This is, of course, a problem not only for the

Polish energy sector but also for the global one. This is just one of many pieces of evidence of the strategic importance of the energy sector in the broadest sense, and there are still many uncertainties worth constantly examining. For this sector, the studies must be made available as soon as the analytical data are available. In our case, updated information for 2021 was published in the second database released at the end of May 2022 and was immediately incorporated into our analysis.

However, the conducted analysis has its limitations. First, it is based on good practices declared voluntarily by companies. Of course, the validity of the statements is verified by the appropriate authority. Still, it can be assumed that some good practices are not reported by companies. Presumably, however, this applies to a small extent to large companies in the energy sector, for which it is in a good interest to demonstrate such practices.

The subject of this analysis is currently undergoing major changes due to the simultaneous occurrence of many modifying factors (epidemic, war, the fight against global warming and environmental pollution). Therefore, it is worth continuing research on good practices related to the energy sector in conditions of rapid changes. Another issue worth attention is the circular economy, an increasingly topical subject both in the world and in the European Union, undertaken in analyses concerning many sectors [81,82], including energy. In a circular economy, it is necessary to focus on the use of renewable energy sources that do not contribute to increasing environmental pollution. Our further research steps go deeper in this direction.

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References

1. World Health Organization. Available online: https://www.who.int/ (accessed on 1 August 2022).
2. Kurtyka, M. O transformacji energetycznej Polski: Strategia rządu, działania ustawodawcy. In *W Drodze do Bezpiecznej i Czystej Energii, Czyli Jak Napisać Rynek na Nowo. 25 lat Regulacji Rynków Energii w Polsce*; Gawin, R., Ed.; Departament Komunikacji Społecznej, Urząd Regulacji Energetyki: Warszawa, Poland, 2022; pp. 129–141. Available online: https://www.ure.gov.pl/pl/25-lecie-ure/publikacja-jubileuszowa/10039,Publikacja-jubileuszowa-Wdrodze-do-bezpiecznej-i-czystej-energii-czyli-jak-napis.html (accessed on 10 July 2022).
3. 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]
4. Prime, H.; Wade, M.; Browne, D.T. Risk and resilience in family well-being during the COVID-19 pandemic. *Am. Psychol.* **2020**, *75*, 631–643. [CrossRef] [PubMed]
5. Żukowska, B.A.; Martyniuk, O.A.; Zajkowski, R. Mobilisation of survivability capital—Family firm response to the coronavirus crisis. *Int. J. Entrep. Behav. Res.* **2021**, *27*, 48–81. [CrossRef]
6. Izzeldin, M.; Muradoğlu, Y.G.; Pappas, V.; Sivaprasad, S. The impact of COVID-19 on G7 stock markets volatility: Evidence from a ST-HAR model. *Int. Rev. Financ. Anal.* **2021**, *74*, 101671. [CrossRef]
7. Dąbek, A. Za nami rekord zakażeń. Co dalej? Ile potrwa piąta fala? *Medonet*. 2022. Available online: https://www.medonet.pl/koronawirus/koronawirus-w-polsce,ile-potrwa-piata-fala-w-polsce--jak-wygladaja-wykresy-z-innych-krajow-,artykul,45164168.html (accessed on 1 August 2022).
8. Łęcka, I.; Kamran, M. Corporate social responsibility (CSR) and sustainable development Goals (SDG). Response of foreign investors in Poland in a COVID-19 pandemic time. In *Theoretical and Practical Aspects of CSR Implementation by Foreign Investors*; Piasecki, R., Gudowski, J., Eds.; Innovatio Press: Lublin, Poland, 2022; pp. 149–171.
9. Wojtyniak, B.; Stokwiszewski, J.; Rabczenko, D.; Madej, T.; Juszczyk, G. *Umieralność Ludności Polski wg Przyczyny Zgonu w Pierwszej Połowie 2021 r. w Porównaniu z Sytuacją w Latach 2017–2019 i 2020*; PZH: Warszaw, Poland, 2022. Available online: https://www.pzh.gov.pl/raport-umieralnosc-ludnosci-polski-wg-przyczyny-zgonu-w-pierwszej-polowie-2021-r/ (accessed on 1 June 2022).
10. Włodarczyk, W.C.; Juszczyk, G. *Zdrowie Publiczne 3.0. Wnioski po Pandemii COVID-19, Perspektywa Globalna*; NIZP-PIB: Warszawa, Poland, 2022. Available online: https://www.pzh.gov.pl/publikacja-zdrowie-publiczne-3-0/ (accessed on 1 June 2022).
11. Korzeb, Z.; Niedziółka, P.; Pankou, D.A. Capital markets and perceptions of sectoral sensitivity to COVID-19. *Ekonomika* **2021**, *37*, 474–488. [CrossRef]

12. Goal 7: Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All. Available online: https://www.un.org/en/chronicle/article/goal-7-ensure-access-affordable-reliable-sustainable-and-modern-energy-all (accessed on 24 June 2022).
13. Roszkowska-Menkes, M. What does CSR really stand for? An analysis of corporate definitions of CSR in Poland/Co naprawdę oznacza społeczna odpowiedzialność biznesu? Analiza definicji CSR najbardziej odpowiedzialnych firm w Polsce. *Res. Pap. Wrocław Univ. Econ.* **2016**, *423*, 94–107. [CrossRef]
14. COVID-19: What It Means for the Energy Industry. PwC. Available online: https://www.pwc.com/us/en/industries/energy-utilities-resources/library/coronavirus-energy-industry-impact.html (accessed on 1 August 2022).
15. Lu, H.; Ma, X.; Ma, M. Impacts of the COVID-19 pandemic on the energy sector. *Appl. Phys. Eng.* **2021**, *22*, 941–956. Available online: https://link.springer.com/content/pdf/10.1631/jzus.A2100205.pdf (accessed on 1 August 2022). [CrossRef]
16. Olabi, V.; Wilberforce, T.; Elsaid, K.; Sayed, E.T.; Abdelkareem, M. Impact of COVID-19 on the Renewable Energy Sector and Mitigation Strategies. *Chem. Eng. Technol.* **2022**, *45*, 558–571. [CrossRef]
17. Werth, A.; Gravino, P.; Prevedello, G. Impact analysis of COVID-19 responses on energy grid dynamics in Europe. *Appl. Energy* **2021**, *281*, 116045. Available online: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7580598/ (accessed on 1 August 2022). [CrossRef]
18. Siksnelyte-Butkiene, I. Impact of the COVID-19 Pandemic to the Sustainability of the Energy Sector. *Sustainability* **2021**, *13*, 12973. [CrossRef]
19. Rutkowska-Tomaszewska, E.; Łakomiak, A.; Stanisławska, M. The Economic Effect of the Pandemic in the Energy Sector on the Example of Listed Energy Companies. *Energies* **2022**, *15*, 158. [CrossRef]
20. Czech, M.; Puszer, B. Impact of the COVID-19 Pandemic on the Consumer Credit Market in V4 Countries. *Risks* **2021**, *9*, 229. [CrossRef]
21. Kacperska, E.; Kraciuk, J. The Effect of COVID-19 Pandemic on the Stock Market of Agri-food Companies in Poland. *Eur. Res. Stud.* **2021**, *24*, 274–290. [CrossRef]
22. CeON Open Science Center Repository (National Polish Digital Repository). Available online: https://depot.ceon.pl/ (accessed on 1 August 2022).
23. Parys, K. Wpływ Skutków Pandemii COVID-19 na Sektor Bankowy w Polsce. Master's Thesis, University of Warsaw, Warsaw, Poland, 2021.
24. Olak, B. Wpływ Pandemii COVID-19 na Branżę Deweloperską. Master's Thesis, University of Warsaw, Warsaw, Poland, 2022.
25. Fallah, S.N.; Mohabbati-Kalejahi, N.; Alavi, S.; Zahed, M.A. Sustainable Development Goals (SDGs) as a Framework for Corporate Social Responsibility (CSR). *Sustainability* **2022**, *14*, 1222. [CrossRef]
26. Stuss, M.M.; Makieła, Z.J.; Herdan, A.; Kuźniarska, G. The Corporate Social Responsibility of Polish Energy Companies. *Energies* **2021**, *14*, 3815. [CrossRef]
27. Davis, K. The case for and against business assumption of social responsibilities. *Acad. Manag. J.* **1973**, *16*, 312–322. Available online: https://www.semanticscholar.org/paper/The-Case-for-and-Against-Business-Assumption-of-Davis/c7babb794c5e70d7db23c45a-679c09e349327ac1 (accessed on 1 August 2022).
28. Beattie, A. The 3 Pillars of Corporate Sustainability. *Investopedia*. 2021. Available online: https://www.investopedia.com/articles/investing/100515/three-pillars-corporate-sustainability.asp (accessed on 1 August 2022).
29. Leonard, D.; McAdam, R. Corporate social responsibility. *Qual. Prog.* **2003**, *36*, 27–32.
30. European Commission. Green Paper: Promoting a European Framework for Corporate Social Responsibility, Commission of The European Communities, Brussel. 2001. Available online: https://ec.europa.eu/commission/presscorner/detail/en/DOC_01_9 (accessed on 10 August 2021).
31. Commission of the European Communities. White Paper: Communication from the Commission Concerning Corporate Social Responsibility: A Business Contribution to Sustainable Development, Office for Official Publications of the European Communities, Brussel. 2002. Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2002:0347:FIN:EN:PDF (accessed on 10 August 2021).
32. European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: A Renewed EU Strategy 2011–2014 for Corporate Social Responsibility, Brussels. 2011. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52011DC0681 (accessed on 10 August 2021).
33. Wróbel, M. Raportowanie społecznej odpowiedzialności w Polsce w świetle unormowań Dyrektywy Parlamentu Europejskiego i Rady 2014/95/UE. *Zesz. Nauk. WSH Zarządzanie* **2016**, *2*, 83–94. [CrossRef]
34. Directive 2014/95/EU of the European Parliament and of the Council of 22 October 2014 Amending Directive 2013/34/EU as Regards Disclosure of Non-Financial and Diversity Information by Certain Large Undertakings and Groups Text with EEA Relevance. 2014. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0095 (accessed on 5 August 2022).
35. Tylec, A. CSR jako obszar raportowania niefinansowego w świetle rozszerzenia zakresu ujawnień. *Zesz. Nauk. Politech. Śląskiej. Organ. I Zarządzanie* **2018**, *127*. Available online: https://www-arch.polsl.pl/wydzialy/ROZ/ZN/Documents/z%20127/026_Tylec.pdf (accessed on 10 August 2022).
36. Dyduch, J.; Krasodomska, J. Determinants of Corporate Social Responsibility Disclosure: An Empirical Study of Polish Listed Companies. *Sustainability* **2017**, *9*, 1934. [CrossRef]

37. Strategia Zrównoważonego Rozwoju Polski do 2025. Available online: http://www.access.zgwrp.org.pl/materialy/dokumenty/StrategiaZrownowazonegoRozwojuPolski/index1.html (accessed on 1 August 2022).
38. Witek-Crabb, A. CSR Maturity in Polish Listed Companies: A Qualitative Diagnosis Based on a Progression Model. *Sustainability* **2019**, *11*, 1736. [CrossRef]
39. Grabara, J.; Dura, C.; Driga, I. Corporate social responsibility awareness in Romania and Poland: A comparative analysis. *Econ. Sociol.* **2016**, *9*, 344–359. [CrossRef]
40. Tylec, A. Społeczna odpowiedzialność—Element zarządzania przedsiębiorstwami w Polsce? Alternative title: Social responsibility—A component of enterprise management in Poland? *Stud. Prawno-Ekon.* **2021**, *120*, 257–274. [CrossRef]
41. The 17 Goals. Available online: https://www.globalgoals.org/goals/ (accessed on 1 August 2022).
42. The 2022 Edition of Tracking SDG 7. The Energy Progress Report. Available online: https://trackingsdg7.esmap.org/downloads (accessed on 1 August 2022).
43. Silva, M.L.; Jacquinet, M.M.; Nobre, Â.L. Corporate social responsibility and management in a glocal context. In *Encyclopedia of Organizational Knowledge, Administration, and Technology*; Khosrow-Pour, M.D.B.A., Ed.; IGI Global: Hershey, PA, USA, 2021.
44. Gunnarsdottira, I.; Davidsdottir, B.; Worrell, E.; Sigurgeirsdottir, S. Sustainable energy development: History of the concept and emerging themes, *Renew. Sustain. Energy Rev.* **2021**, *141*, 110770. [CrossRef]
45. Tiep, L.T.; Huan, N.Q.; Hong, T. Role of corporate social responsibility in sustainable energy development in emerging economy. *Int. J. Energy Econ. Policy* **2021**, *11*, 172–186. [CrossRef]
46. Nair, R.; Viswanathan, P.K.; Bastian, B.L. Reprioritising Sustainable Development Goals in the Post-COVID-19 Global Context: Will a Mandatory Corporate Social Responsibility Regime Help? *Adm. Sci.* **2021**, *11*, 150. [CrossRef]
47. ElAlfy, A.; Palaschuk, N.; El-Bassiouny, D.; Wilson, J.; Weber, O. Scoping the Evolution of Corporate Social Responsibility (CSR) Research in the Sustainable Development Goals (SDGs) Era. *Sustainability* **2020**, *12*, 5544. [CrossRef]
48. Polska na Drodze Zrównoważonego Rozwoju. Raport 2020. SDG_GUS. Available online: https://raportsdg.stat.gov.pl/2020/ (accessed on 21 June 2022).
49. Polska na Drodze Zrównoważonego Rozwoju. Raport 2021. SDG-GUS. Available online: https://raportsdg.stat.gov.pl/ (accessed on 21 June 2022).
50. 60 Dobrych Praktyk CSR Na 60 Lat KGHM | KGHM Strona Korporacyjna. Available online: https://kghm.com/pl/60praktykCSR (accessed on 21 May 2022).
51. Przewodnik Dobrych Praktyk Społecznej Odpowiedzialności Biznesu. 2021. Available online: https://fundacjabin.pl/wp-content/uploads/2021/08/Rowna_firma_przewodnik_dobrych_praktyk_2021-07-30_p2.pdf (accessed on 21 May 2022).
52. Baza Dobrych Praktyk—www.dobrepraktyki.pl. Available online: https://www.dobrepraktyki.pl/index.php?p1=16&tj=1 (accessed on 24 April 2022).
53. Responsible Business in Poland. Best Practices. Available online: https://odpowiedzialnybiznes.pl/english/ (accessed on 21 May 2022).
54. Responsible Business Forum. Dobre praktyki CSR w Polsce. Available online: https://odpowiedzialnybiznes.pl/dobre-praktyki/ (accessed on 21 May 2022).
55. Turoń, K.; Golba, D.; Czech, P. The analysis of progress CSR good practices areas in logistic companies based on reports “Responsible Business in Poland. Good Practices” in 2010–2014. *Sci. J. Sil. Univ. Technol. Ser. Transp.* **2015**, *89*, 163–171. [CrossRef]
56. Czubała, A. Corporate Social Responsibility in Marketing. *Forum Sci. Oecon.* **2016**, *4*, 103–111. Available online: http://ojs.wsb.edu.pl/index.php/fso/article/view/239/183 (accessed on 1 August 2022).
57. Krasodomska, J.; Cho, C.H. Corporate social responsibility disclosure: Perspectives from sell-side and buy-side financial analysts. *Sustain. Account. Manag. Policy J.* **2017**, *8*, 2–19. [CrossRef]
58. Koładkiewicz, I. Corporate social responsibility in Poland: The Responsible Business Forum 2002–2007 report perspective. *Soc. Responsib. J.* **2009**, *5*, 48–61. [CrossRef]
59. Hys, K.; Hawrysz, L. CSR in Poland as an important foundation of modern society. *Manag. Stud.* **2013**, *1*, 27–33.
60. Hąbek, P. Evaluation of sustainability reporting practices in Poland. *Qual. Quant.* **2014**, *48*, 1739–1752. [CrossRef]
61. Zalewska, M.E. The Impact of Incentives on Employees to Change Thermostat Settings—A Field Study. *Energies* **2021**, *14*, 5315. [CrossRef]
62. Stawicka, E. Sustainable Business Strategies as an Element Influencing Diffusion on Innovative Solutions in the Field of Renewable Energy Sources. *Energies* **2021**, *14*, 5453. [CrossRef]
63. 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. [CrossRef]
64. Adler, R.; Ewing, J.; Taylor, P. Citation Statistics. *Statist. Sci.* **2009**, *24*, 1–14. [CrossRef]
65. Stawicka, E.; Paliszkiewicz, J. Social Media in Communicating about Social and Environmental Issues—Non-Financial Reports in Poland. *Information* **2021**, *12*, 220. [CrossRef]
66. Raport Syngeos. Available online: https://syngeos.pl/raport/ (accessed on 21 May 2022).
67. EcoReporters.pl. Jak Poznać, że Stary Piec to Kopciuch, co Jest Wskazówką? Available online: https://ecoreporters.pl/2022/jak-poznac-ze-stary-piec-to-kopciuch/ (accessed on 21 July 2022).

68. Kos, A.; Gudowski, J. Społeczna odpowiedzialność biznesu na Lubelszczyźnie w świetle badań ankietowych. In *Wybrane Problemy Rozwoju Społeczno-Gospodarczego w Nauce i Praktyce*; Skrzypczak-Ahmed, S., Szafarczyk, A., Eds.; Innovatio Press: Lublin, Poland, 2019; pp. 41–55.
69. Our World in Data. Available online: https://ourworldindata.org/coronavirus#explore-the-global-situation (accessed on 21 June 2022).
70. Raporty, C.S.R. Grupa Energa. Available online: https://grupa.energa.pl/otoczenie/raporty-csr (accessed on 21 May 2022).
71. Chodnicka-Jaworska, P. ESG as a Measure of Credit Ratings. *Risks* **2021**, *9*, 226. [CrossRef]
72. Boldeanu, F.T.; Clemente-Almendros, J.A.; Tache, I.; Seguí-Amortegui, L.A. Is ESG Relevant to Electricity Companies during Pandemics? A Case Study on European Firms during COVID-19. *Sustainability* **2022**, *14*, 852. [CrossRef]
73. Chodnicka-Jaworska, P. Environmental, Social, and Governance Impact on Energy Sector Default Risk—Long-Term Issuer Credit Ratings Perspective. *Front. Energy Res.* **2022**, *10*, 817679. [CrossRef]
74. Zieliński, M.; Jonek-Kowalska, I. Does CSR Affect the Profitability and Valuation of Energy Companies? An Example from Poland. *Energies* **2021**, *14*, 3668. [CrossRef]
75. Codogni, I. The chances and limitations of applying a CSR strategy in Polish enterprises. *Ann. Ethics Econ. Life* **2018**, *21*, 111–123. [CrossRef]
76. Suska, M. Environmental Corporate Social Responsibility (ECSR) on the Example of Polish Champion Oil, Gas and Mining Companies. *Sustainability* **2021**, *13*, 6179. [CrossRef]
77. Roczniki Statystyczne. GUS: Warszawa, Poland. Available online: https://stat.gov.pl/obszary-tematyczne/roczniki-statystyczne/ (accessed on 21 May 2022).
78. European Financial Congress. Available online: https://www.efcongress.com/ (accessed on 21 July 2022).
79. Statistics Poland. Available online: https://stat.gov.pl/en/regional-statistics/classification-of-territorial-units/administrative-division-of-poland/ (accessed on 21 July 2022).
80. Pollach, I.; Johansen, T.; Nielsen, A.; Thomsen, C. The integration of CSR into corporate communication in large European companies. *J. Commun. Manag.* **2012**, *16*, 204–216. [CrossRef]
81. Fortunati, S.; Morea, D.; Mosconi, E.M. Circular economy and corporate social responsibility in the agricultural system: Cases study of the Italian agri-food industry. *Agric. Econ.* **2020**, *66*, 489–498. [CrossRef]
82. Morea, D.; Fortunati, S.; Martiniello, L. Circular economy and corporate social responsibility: Towards an integrated strategic approach in the multinational cosmetics industry. *J. Clean. Prod.* **2021**, *315*, 128232. [CrossRef]

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Article

Employment and Competencies of Employees in the Energy Sector in Poland

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Abstract: Employment and the competencies of employees in the energy sector are coming into particular prominence in economies around the world. It is one of the few sectors positively affected by the COVID-19 pandemic. As a result, a significant global change in the awareness of society occurred in favor of increasing pro-health and pro-environmental activities, which can be seen in the green transformation. Poland can also boast such changes in recent years, as evidenced by the dynamic development of renewable energy sources (boom for photovoltaics) and the increase in prosumption. Correlated with this is the increase in demand for employees with specific competencies, the so-called multi-competencies that are a compilation of technical, business, and soft and hard competencies, as well as interdisciplinary ones. The paper emphasizes the need to better adjust the education system to the real needs of the labor market in a turbulent environment with the use of the Sectoral Qualifications Framework in Energy, developed in cooperation with stakeholders from the industry. Therefore, the authors analyzed the employment structure in the energy sector in Poland, with particular emphasis on the factors and conditions of this structure and made an attempt to identify and create a competency profile of employees in this area. For the purposes of this article, two key research problems were formulated: What are the key competencies of employees in the energy sector? How is employment changing in this area? The following research hypothesis was also put forward: The transformation of the energy sector towards green energy affects the increase in employment in this area and the increase in the demand for soft competencies. The analysis was based on statistical data, reports, job advertisements, and a review of the results of empirical research to date.

Keywords: energy; green transformation; green energy; energy transformation; low-carbon economy; competencies; sectoral qualifications framework for energy; employment; labor market in Poland

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1. Introduction

Energy shapes all economic and living activities of all humankind. Nature provides inexhaustible energy resources, such as water, wind, solar radiation, geothermal energy, biomass, biogas, and biofuels, which constitute ecologically beneficial alternatives to the ever-exploited resources of coal, oil, or gas [1].

The energy sector is one of those few "immune" to the effects of the COVID-19 pandemic. As shown by statistics and scientific research, employment in this area is systematically increasing all over the world. The pandemic significantly changed and increased social awareness and increased empathy and sensitivity to both health and the natural environment.

Therefore, the development of the energy sector and the ensuing increase in employment result mainly from the green transformation and are related to the development of such energy branches as solar energy (photovoltaic installations, solar collectors, heat pumps) and an increase in the use of biogas, hydropower, wind energy, or biomass. The support offered by the European Union for green energy is also crucial. It has already contributed to the accelerated modernization of the existing energy systems in Europe as well as the emergence of new products and services in this area.

The changes in employment caused by technological and technical changes triggered by the necessity to transform the energy system (particularly the electricity sector) into a post-coal one remain the focus of many studies. However, only a handful of the researchers work with forecasts or provide detailed information at the country or sector level while reporting the results broken down by competency level and capital expenditure. It must be noted that it is worth distinguishing between these categories in order to obtain a more differentiated picture of the demand for labor in various stages of transformation. This approach to the problem enables an early and appropriate response to future labor demand. Therefore, an attempt can be made to rationally plan appropriate expenditure for a given phase with the help and characteristic intensity of appropriate measures related to employment, retraining, education, and vocational training. This helps to address persisting or potentially worsening labor market imbalances and inequalities and to create a post-carbon transformation in line with the principles of fair transition [2].

The development of the energy market is associated not only with the aforementioned increase in employment (creation of new positions and jobs) but primarily with the formation of new employee competencies in the labor market. These currently include multidimensional, interdisciplinary, and specialist competencies as well as soft competencies.

The aim of this article is to analyze the employment structure of employees in the energy sector in Poland, allowing for the factors and conditions of this structure, and to attempt to identify and create a competency profile of employees in this area. The authors have formulated the following research inquiries: What are the key competencies of employees in the energy sector? How is employment changing in this area? A research hypothesis was formulated: The transformation of the energy sector towards green energy affects the increase in employment in this area and the increase in the demand for soft competencies. The analysis was based on statistical data, reports, job advertisements, and a review of the results of empirical research to date.

2. Energy in Poland

One of the principal problems for the countries of the European Union and the world is climate change and the deteriorating condition of the natural environment. In order for technological progress not to endanger the health and life of the population, it has become necessary to pursue an appropriate environmental policy [3]. The action plan called "The European Green Deal" is intended to make Europe a neutral continent in terms of greenhouse gas emissions by 2050 while maintaining a competitive, modern, and sustainable economy. The possibilities of implementing this new strategy in the European community are being awaited in all economic and social areas, including the energy sector [4,5]. This sector plays an important role in the economy, and energy and its resources are becoming strategic products that have a real impact on almost all elements of the proper functioning of the state [6].

Energy is currently considered to be one of the key industries all over the world. It covers the production and distribution of both electrical and heat energy. There are two key types of energy production, i.e., conventional energy, C.E. (fuel combustion), and non-conventional energy, N.C.E. (alternative sources), which are presented in Figure 1.

Compared to traditional (fossil) sources, obtaining energy from renewable sources is more environmentally friendly. The escalation of the use of renewable energy sources reduces the harmful impact of energy on the natural environment, mainly by reducing the emission of harmful substances, particularly greenhouse gases [8].

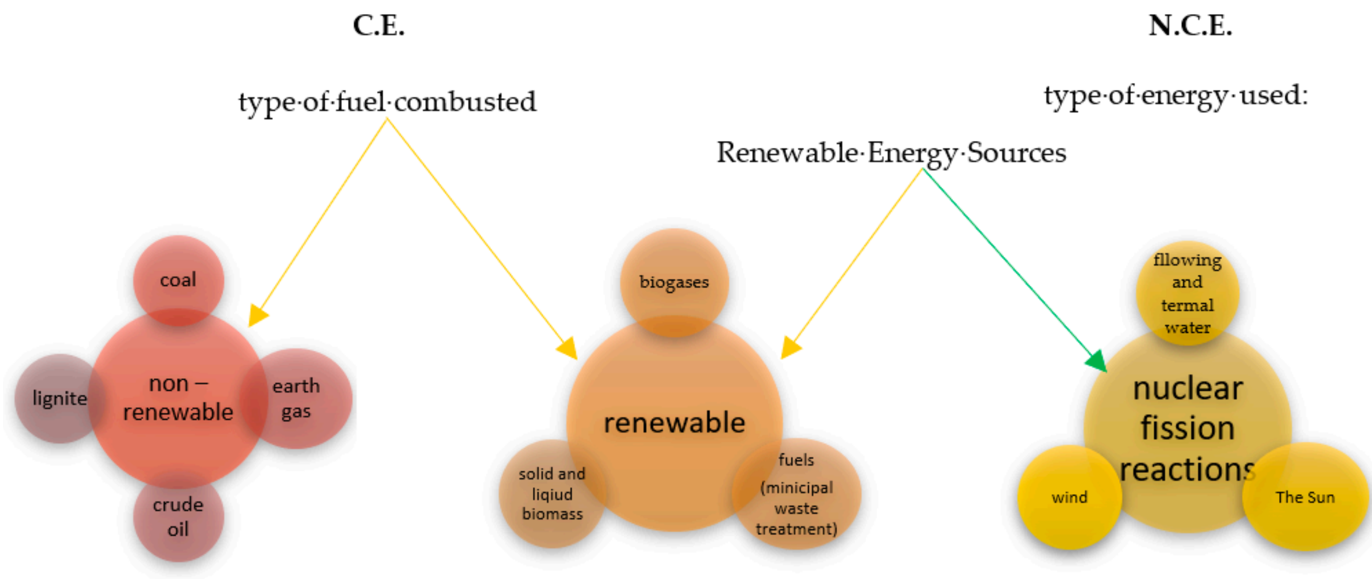

Figure 1. Classification of Energy Production. Authors' own study based on Source: [7].

The "Polish Energy Foresight" report presents the results of the research based on the Delphi method that is used to predict long-term processes and phenomena. The aim of this research was to capture the way the energy transformation in Poland is shaping up. Among the formulated theses, the researchers indicate the following four key ones, i.e.,

(1) Withdrawal from hard coal mining for energy purposes is of the greatest importance for the energy transformation in Poland (93% of experts);
(2) A conducive factor for the development of the energy transformation in Poland is the level of domestic and EU funding (73 points per 100);
(3) The key barrier to the development of the energy transformation in Poland is the instability of its political situation and authority structures;
(4) The experts formulated the conclusion that the building of a nuclear power plant in Poland and an increase in gas consumption are both very unlikely ever to happen (26% of the experts) [9].

For several years now, the global economy has seen a steady increase in the use of non-conventional energy. The precursors to the development of this energy sector are mainly those European Union countries that first ratified the Kyoto Protocol—an international treaty on an agreement to combat global warming [1]. Additionally, comprehensive statistics in the field of renewable energy are systematically developed by the International Renewable Energy Agency (IRENA). Globally, the share of renewable energy is growing at an average of 7.6% per year, with the exception of Asia, where it has reached 54%. As shown in IRENA reports, Poland follows global trends—solar and wind energies currently take the strongest position [10].

A draft of Poland's Energy Policy by 2040 was presented In September 2020 (PEP 2040).

The share of coal in the energy consumption structure will reach no more than 56% in 2030, and with increased prices of CO_2 emission allowances, it may even drop to 37.5%. In 2040, the share of coal will drop to 28%. Currently, coal-fired power plants produce approx. 70% of electricity.

The share of renewable energy sources will inevitably increase in all sectors and technologies (Figure 2), and in 2030 this share will amount to at least 23% of the gross final energy consumption:

- not less than 32% in the power industry (mainly wind energy and photovoltaics);
- 28% in heating (increase by 1.1 percentage point, year to year);
- 14% in transport (with a large contribution of electromobility).

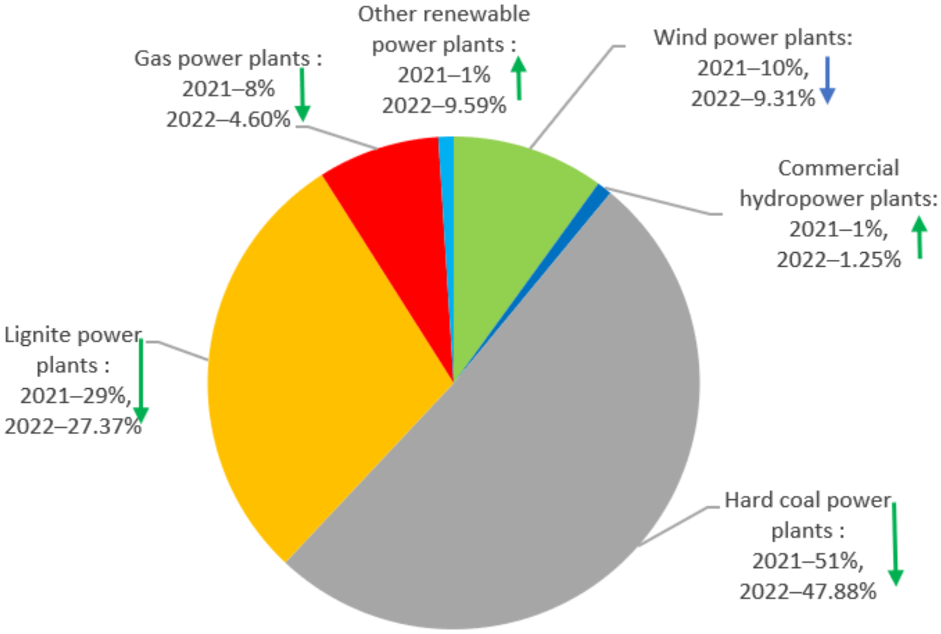

Figure 2. Electricity production structure in Poland as of December 2021 RE and July 2022. Authors' own study based on Source based on PSE (Polish Power Systems) data. Source: [11].

In addition, there will be a significant increase in installed capacity in photovoltaics: approx. 5–7 GW in 2030 and approx. 10–16 GW in 2040.

Offshore wind energy will be implemented from 2025, and the installed capacity will reach approx. 5.9 GW in 2030 and approx. 8–11 GW in 2040. On the other hand, onshore wind energy will reach approx. 8–10 GW in 2030.

In 2033, the first nuclear unit with a capacity of 1–1.6 GW will be launched, and the following ones will be put into operation within 2–3 years—the entire nuclear program assumes the construction of 6 units by 2043.

The most anticipated innovations in the energy sector include:

- energy storage technologies;
- smart measurement and energy management systems;
- electromobility and alternative fuels;
- hydrogen technologies [11].

Polska Grupa Energetyczna (PGE) is involved in investments and projects related to the green transformation of the energy sector in Poland toward low-emission. Examples include the construction of offshore wind farms in the Baltic Sea, two gas-and-steam units at Dolna Odra Power Plant, and photovoltaic farms (currently, around 3000 ha of land have been allocated for this purpose) [12].

The analysis of the Polish energy market, carried out by Forum Energii (Energy Forum) and presented in the "Polish energy sector 2050. 4 scenarios" report, outlines four possible paths of development of the sector in the context of EU obligations in the perspective of up to 30 years, including the economic and environmental effects as well as the impact on the national economy.

Scenario 1, "The Coal Scenario", assumes the construction of new mines (predicted RES share in 2050: 17%).

Scenario 2, "The Diversified Scenario With Nuclear Energy", is a mix of energy technologies (predicted RES share in 2050: 38%).

Scenario 3, "The Diversified Scenario Without Nuclear Energy", is an increased production of natural gas and renewable energy sources (predicted RES share in 2050; 50%).

Scenario 4, "The Renewable Scenario", is the withdrawal from coal energy (predicted RES share 73%).

Comparing the above scenarios, their total system costs are similar—approx. 6%. The significant differences are in the level of CO_2 emission reduction (scenario 1 by 7%, 2–65%, 3–68%, 4–84%), and the level of providing energy security (the renewable scenario has the highest level of independence) [13].

3. Employment of Workers in the Energy Sector in Poland

The number of jobs in the broadly understood energy sector (electricity, heating, transport, water desalination) is likely to increase worldwide to 134 million in 2050 (57 million in 2020), assuming that 100% of the energy in the world will be obtained from renewable sources by then, which is one of the goals of the Paris Agreement (a climate agreement, which assumes that the European Union's economy will become climate neutral by 2050). Such a transformation of the energy market will definitely require more qualified and competent employees, e.g., in the field of specialist servicing of renewable energy sources [14].

The changes brought about by individual countries' efforts to achieve the climate neutrality in question will have both positive and negative consequences. The first one will be a decline in demand for high-carbon products and services and the related changes in capital allocation, and the second key consequence will be changes in global labor markets. On the one hand, there will be a decline in employment in sectors that are directly and indirectly related to the extraction of fossil fuels, and on the other hand, an increase in the demand for employees in sectors related to renewable energy, hydrogen, and biofuels. According to forecasts, there will be an increase in the demand for around 200 million jobs and a decline for around 185 million jobs worldwide [15].

Shifting resources from high-carbon to low-carbon activity, therefore, requires flexible labor and product markets. Efficient financial markets that will support the withdrawal from fossil fuel energy and the linking of physical capital with low-carbon products, as well as restructuring and manufacturing processes, are also important. Additionally, an effective framework, such as good research conditions, the adaptation of new skills in the workforce, and a favorable environment for the construction and development of new technologies (including through R&D subsidies), will facilitate the structural changes required to implement green production practices [16] and creation of new jobs.

At present, when entering one of the largest advertising portals in Poland—www.pracuj.pl (accessed on 2 April 2022) and searching for *energy*, there are nearly 600 job offers for various positions in this area in companies throughout the country. These offers include energy advisor, assistant designer, project manager, photovoltaics specialist, energy documentation specialist, (energy) technological expert, renewable energy consultant, cost estimator in the energy department, heat and process energy engineer, energy efficiency manager, emission measurement coordinator, and many more. For example, Polska Grupa Energetyczna PGE is currently looking for employees for 25 jobs (as of 2 April 2022). Another large company, Tauron Polska Energia S.A., has as many as 147 job offers [17].

The increase in employment in the energy sector in Poland has been systematically noticeable for several years. Admittedly, the employment structure is changing in connection with the green transformation and modernization of this area. The transition from a coal-based economy to a low-carbon economy requires retraining employees and creating new, green jobs.

The energy transformation in the world, including Poland, has become a fact. It has and will continue to have a significant impact on the increase or decrease in employment in particular sectors and groups of employees in the coming years. The modernization of the energy sector in Poland, which is aimed at low-carbon emissions, is related to the withdrawal from the coal economy, where employment in the country amounted to 77.7 thousand people as of the end of 2021, and at the end of June 2022, this number was 74.8 thousand [18].

The impact of the energy transformation on the increase or decrease in employment in individual sectors and groups of employees in Poland is a dynamic phenomenon. Currently, the energy market in Poland is experiencing a noticeable increase in the demand for employees, for example, in the area of traditional energy sources. This is happening, most of all, in connection with the need to modernize or replace the energy infrastructure. On the other hand, there is a noticeable decrease in the demand for employees operating energy installations based on mine raw materials, coal mining, and operating and servicing mining machines. In addition, along with a significant reduction in coal extraction and the liquidation of mines, specialists will be in demand, for example, in the rehabilitation of post-mining areas or workers performing fieldwork. Focusing the energy policy on low-carbon emissions is and will also be associated with the need to develop offshore and onshore wind farms or photovoltaics, so designers, producers, installers, service technicians, and advisers in this area will also be sought after. In connection with the energy transformation, the construction sector will also look especially for manufacturers of thermal insulation products, contractors, energy auditors, and energy advisors. On the other hand, agriculture is gradually moving away from cattle breeding and feed production in favor of plant cultivation, organic food production, nutritional consulting, dietetics, or food processing. The impact of this energy transformation is also noticeable in the transport sector. The departure from passenger cars and trucks with traditional drives in favor of electric vehicles and the development of public transport will increase the demand for specialists in this area, including specialists for the repair of electric passenger cars working in the construction and operation of charging stations, battery disposal specialists and bus drivers, tram drivers, train drivers, logisticians of journeys and parking systems, specialists in servicing equipment and managing the placement of vehicles [19].

A great deal of recent research and reports on the performance of the energy sector has focused on employment generated by investment. When planning their energy future, governments are also interested in the benefits of job creation and the possible identification of skill shortages that could arise from a large energy program. Employment created or supported by the energy sector is often a problem when government support is considered or provided [20]. The energy transformation affects the labor market not only directly in the energy sector but also in other related sectors, such as the mining industry, transport, construction, and agriculture. The increase in demand for employees is noticeable and understandable, primarily in connection with the development and formation of new offshore and onshore wind farms, photovoltaic farms, electrical vehicles, low-emission machinery and equipment, or the production of ecological food. In turn, the decline in the demand for employees mainly affects traditional power engineering based on fossil raw materials or the coal mining sector and other branches of the economy based on it. On the other hand, it stimulates an increase in the demand for employees, e.g., for reclamation of post-mining sites, and creates considerable opportunities for retraining and changing the employees' professional profiles, which will, in turn, enable balancing the demand and supply for employees on the labor market and minimizing the negative effects of the energy transformation. The RES sector creates a variety of jobs in production, services, and construction which require a range of qualifications and skills. Its development not only increases the number of jobs but also improves their quality in the industry. The increase in employment requires a new investment momentum, which will be determined by the dynamics of jobs created by, e.g., the wind energy industry in the next decade; this dynamic will largely be determined by the amount of expenditure for the building of offshore wind farms [21].

Before 2016, the location of many wind farms was acceptable because these structures were built prior to the adoption of the Act of 20 May 2016 On Investments In Wind Farms [22]. The provisions of the introduced act stipulated that the distance of wind farms from residential buildings and any forms of environmental protection may not be less than "ten times the height of the wind farm measured from the ground level to the highest point of the structure, including technical elements, in particular the rotor with blades"—the so-called Rule 10H. Therefore, newly located windmills (or wind farms) should be located at a distance of about 1.5–2 km from residential buildings and protected natural areas or reserves. That rule basically limited or halted any investments in this area. The situation changed on 5 July 2022, when the Polish government adopted a bill that amended the above-mentioned legal act. This was dictated by the state's energy policy related to the diversification of energy sources. Rule 10H is supposed to continue to maintain the basic rule for locating a new wind farm (exclusively on the basis of the Local Zoning Plan—LZP). Pursuant to this provision, the local zoning plan can determine a different distance of the wind farm from residential buildings considering the range of the wind farm's impact while maintaining the absolute minimum safety distance specified in the draft amendment. The removal of the 10H barrier for wind farms will contribute to "unblocking" the wind industry and creating new jobs, but certain "support" in stopping such a strong dynamic of energy price growth is also to be expected.

4. Competency Profile of Employees in the Energy Sector

Production of clean energy is expected to continue to grow in the coming years, but it has been observed that the supply and demand for labor in the energy sector are not consistent. According to estimates, there are and will be recorded surpluses and shortages in certain important skills in the labor market in the energy sector. They are caused by the lack of specialization in workers or the location of the available labor supply and the required location of the labor demand. These situations often do not coincide [23]. Although the mobility of employees or the desire to retrain or acquire new skills is no longer as significant a limitation as it was several years ago, due to wages, social, and family conditions, it may regionally constitute a barrier to development.

The adjustment of the knowledge, skills, and competencies of employees in the context of dynamic changes taking place in the labor market in a situation of uncertainty, e.g., the current pandemic, poses a real challenge for the education system. The idea of lifelong learning is also becoming more and more rooted in Poland's and other countries' realities. This idea is related not only to the development and deepening of existing knowledge and skills but also to the need to acquire and shape new competencies and even retrain employees in accordance with market trends. In accordance with the Act of 22 December 2015 on the Integrated Qualifications System IQS (i.e., Journal of Laws 2020, item 226), it is implemented in Poland, and its key tool is the Polish Qualifications Framework (PQF), analogous to the European Qualifications Framework (EQF). Under PQF, first and second-degree characteristics are in force, which are determinants of curricula that indicate key qualifications obtained in general education, university education, and vocational education and training. Additionally, in order to better allow for the specificity of a given industry or sector, the Sectoral Qualification Framework (SQF) was introduced in Poland as part of the characteristics of the second level PQF, and this is also the case in the energy sector. Its essence comes down to allowing for industry-specific terminology and language, which significantly improves communication with market entities. The great value of SQF is that stakeholders from a given sector or industry participate in its creation (high level of practice) [24]. Moreover, according to the authors, the analysis of competencies and qualifications, as well as employment determinants in the energy sector, indicates several key problems that are presented in Figure 3.

Summarizing the competency profile and factors determining employment in the energy sector, the issues of gender equality and the remuneration system should also be emphasized. Including the gender factor in personnel selection, employment, upgrading qualifications, and employment restructuring would increase the level of women's representation in the energy sector [25]. With regard to remuneration for all employees, it would be helpful to define a standard that should be subject to evaluation and result from the current conditions of the company and employee development.

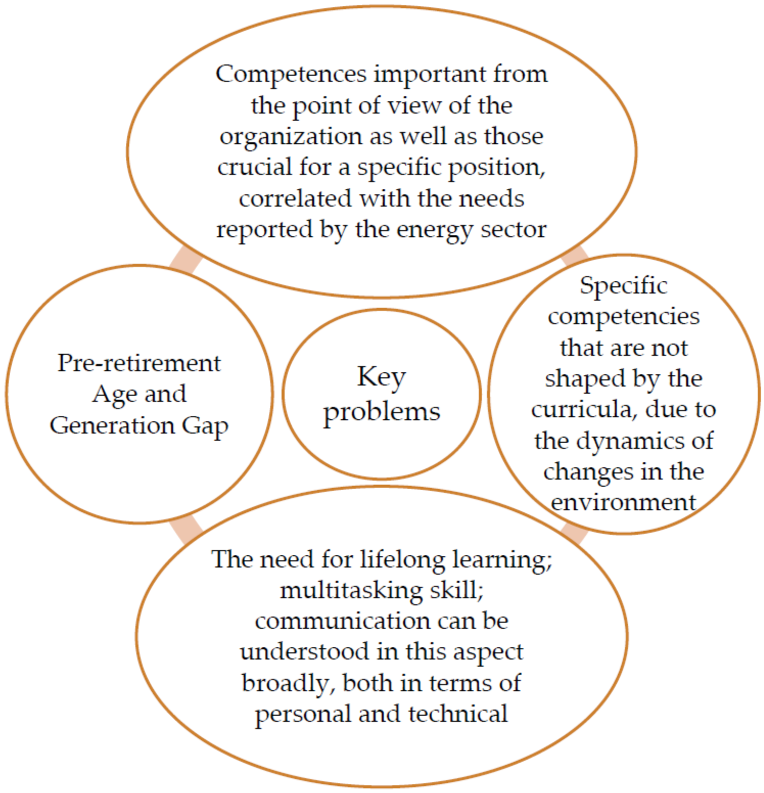

Figure 3. Identification of employment problems in the energy sector—selected aspects. Source: authors' own study.

5. The Use of SQFE

Sectoral Qualification Framework for Energy is a response to the needs reported by the broadly understood participants of the energy market (from producers, through the education system, to energy recipients). It concerns the identification and cataloging of competencies and professional tasks in the areas of production (generation), conversion, transmission, storage, and distribution of energy. These issues relate to energy obtained using conventional methods and that from renewable sources

SQFE is used in four main areas and includes:

1. HR processes (job descriptions, recruitment process, selection, assessment and development of competencies, relocation of employees within company structures);
2. education and training (diagnosis of competencies, better adjustment of curricula, internships and courses to the expectations of the labor market, increased flexibility);
3. public orders (including competency requirements in administration);
4. balance of competencies.

According to SQFE, the competency profile of an employee in the energy sector in Poland includes knowledge, skills, and competencies. They are used primarily in main focus areas, i.e., design and planning, infrastructure building and maintenance, manufacturing, storage and delivery of energy, customer needs, energy carriers, and working media, environment, and safety. Their importance is particularly emphasized in the areas of social competencies such as communication, ethics, decision-making, responsibility for quality and safety, and responsibility for the environment [24].

As pointed out by experts, professions that will emerge as new or those with increasing popularity (hence the need to shape new competencies) will concern the employees in the fields of green economy and green energy, the so-called 'green jobs'. These include the aforementioned renewable energy, nuclear energy, recycling and rational waste management, as well as the production of structurally new materials. Therefore, the need for the creation of jobs and competencies in professions related to infrastructure investments and those in the construction sector, as well as urban planners, energy system strategists, specialists in digital infrastructure, and geo-engineers [26], will also remain correlated. Furthermore, it is estimated that the labor market (and even more so its individual sectors) will see an increase in the importance of soft skills related to the creation of new services, including creativity, communication skills, ability to work in a group, and self-awareness of the impact of one's actions on team performance as well as effective time management. They are now gaining in importance, especially now that the organization of work after the COVID-19 pandemic is different and will continue to evolve (increasing use of remote work, data digitization, updating, and security).

The changes in the labor market caused by the COVID-19 pandemic were pointed out by, e.g., Lu, Ma, and Ma [27], Adamowicz [28], Eichhorst, Marx, and Rinne [29], and Ciołek [30]. When analyzing the aforementioned job offers in the energy sector on www.pracuj.pl, several key competencies expected by employers from job candidates can be noticed. These include technical secondary or university education, experience in the industry, personal culture, communication skills, relationship building, teamwork, including team management, design, planning, and good command of computer skills and engineering programs. Additionally, hard and technical competencies are, of course, expected, depending on the specifics of a given position. In conclusion, knowledge, skills, and competencies have been included in the SQFE.

6. Conclusions

The energy sector in Poland can undoubtedly see visible changes related to the inevitable need to modernize its individual areas. The COVID-19 pandemic did not slow this process down—quite the contrary. The public awareness of the need to undertake more and more efforts for a healthy lifestyle and care for the natural environment has increased. There is a development of areas related to pro-environmental activities, which is noticeable in the domestic market, e.g., in recent years' photovoltaic boom. Prosumption, the production of electricity and its consumption by single-family households and farms, has gained importance. The development of the energy sector is correlated with the growing demand for employees with specific competencies. These include the so-called multi-competencies that combine technical, business, soft and hard competencies, and also interdisciplinary ones. Employees with expertise in investment, team management, and communication are needed. Graduates of energy industry schools and technical secondary schools, as well as specialists with higher education, including engineers, are highly sought-after. In order to better adjust the education system to the real needs of the labor market in a turbulent environment, the Sectoral Qualifications Framework in Energy was developed in cooperation with stakeholders from the industry.

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References

1. Graczyk, A.; Wielewska, I.; Piaskowska-Silarska, M. *Rozwój Odnawialnych Źródeł Energii w Polsce. Problemy Bezpieczeństwa Energetycznego i Lokalnego Wykorzystania Zasobów*; Texter: Warsaw, Poland, 2017.
2. Černý, M.; Bruckner, M.; Weinzettel, J.; Wiebe, K.; Kimmich, C.; Kerschner, C.; Hubacek, K. Employment effects of the renewable energy transition in the electricity sector: An input-output approach. *ETUI Res. Pap. Work. Pap.* **2021**, *14*, 1–70. Available online: https://ssrn.com/abstract=4013339 (accessed on 12 June 2022). [CrossRef]
3. Tutak, M.; Brodny, J.; Bindzár, P. Assessing the Level of Energy and Climate Sustainability in the European Union Countries in the Context of the European Green Deal Strategy and Agenda 2030. *Energies* **2021**, *14*, 1767. [CrossRef]
4. Tucki, K.; Mruk, R.; Botwińska, K.; Mieszkalski, L.; Kulpa, K.; Gruz, Ł.; Wiszowata, K. Modelling of CO_2 emissions in driving tests on the example of a diesel engine powered by biofuels. *Rocz. Ochr. Środowiska* **2021**, *23*, 744–763. [CrossRef]
5. Gunfaus, M.T.; Waisman, H. Assessing the adequacy of the global response to the Paris Agreement: Toward a full appraisal of climate ambition and action. *Earth Syst. Gov.* **2021**, *8*, 100102. [CrossRef]
6. Pawełczyk, M. *Publicznoprawne Obowiązki Przedsiębiorstw Energetycznych Jako Instrument Zapewnienia Bezpieczeństwa Energetycznego w Polsce*; Wydawnictwo A. Marszałek: Toruń, Poland, 2013.
7. Źródła Energii w Polsce, Content Plus, CC BY 3.0. Available online: https://zpe.gov.pl/a/zrodla-energii-w-polsce/DZ9m3Dvd0 (accessed on 14 February 2022).
8. Barent-Kowalska, G.; Dąbrowska-Ładno, J.; Jurgaś, A.; Kacperczyk, G.; Sułkowski, M.; Tkaczyk, W.; Wnuk, R. *Zasady Metodyczne Badań Statystycznych z Zakresu Źródeł Odnawialnych*; Główny Urząd Statystyczny: Warszawa, Poland, 2016.
9. Dębkowska, K.; Juszczak, A.; Maj, M.; Szymańska, A. *Foresight Energetyczny Polski*; Polski Instytut Ekonomiczny: Warszawa, Poland, 2021; pp. 4–5. Available online: https://pie.net.pl/wp-content/uploads/2021/10/PIE-Raport_foresight_energetyczny_PL_2021.pdf (accessed on 17 February 2022).
10. International Renewable Energy Agency. *Renewable Capacity Statistics 2020*; IRENA: Abu Dhabi, United Arab Emirates, 2020; Available online: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Mar/IRENA_RE_Capacity_Statistics_2020.pdf (accessed on 17 February 2022).
11. Struktura Produkcji Energii Elektrycznej. Aktualizacja. Available online: https://www.rynekelektryczny.pl/produkcja-energii-elektrycznej-w-polsce/ (accessed on 25 August 2022).
12. Artykuł PGE. Inwestycje PGE w 2021 r. Zmieniają Polską Energetykę. Available online: https://www.wnp.pl/energetyka/inwestycje-pge-w-2021-r-zmieniaja-polska-energetyke,520271.html (accessed on 30 March 2022).
13. Ecke, J.; Steinert, T.; Bukowski, M.; Śniegocki, A. Polski Sektor Energetyczny 2050. 4 Scenariusze. *Forum Energii*. 2017, p. 5. Available online: https://forum-energii.eu/public/upload/articles/files/Polski-sektor-energetyczny-2050_druk.pdf (accessed on 17 February 2022).
14. Ram, M.; Osorio-Aravena, J.C.; Aghahosseini, A.; Bogdanov, D.; Breyer, C. Job creation during a climate compliant global energy transition across the power, heat, transport, and desalination sectors by 2050. *Energy* **2022**, *238*, 121690. [CrossRef]
15. Krishnan, M.; Samandari, H.; Woetzel, J.; Smit, S.; Pacthod, D.; Pinner, D.; Nauclér, T.; Tai, H.; Farr, A.; Wu, W.; et al. *The Net-zero Transition: What It would Cost, What It could Bring*; Special Report; McKinsey & Company: Poznań, Poland, 2022; Available online: https://www.mckinsey.com/business-functions/sustainability/our-insights/the-economic-transformation-what-would-change-in-the-net-zero-transition (accessed on 17 February 2022).
16. European Central Bank. *Climate Change and Monetary Policy in the Euro Area*; ECB Strategy Review; Occasional Paper Series; European Central Bank: Frankfurt, Germany, 2021; Volume 271, pp. 1–193. Available online: https://www.ecb.europa.eu/pub/pdf/scpops/ecb.op271~{}36775d43c8.sv.pdf (accessed on 19 June 2022).
17. Tauron. Oferty Pracy Tauron. 2022. Available online: https://www.tauron.pl/tauron/o-tauronie/kariera/oferty-pracy?page=9#search-results (accessed on 2 April 2022).
18. Polski Rynek Węgla. Agencja Rozw. Przemysłu. 2022. Available online: https://polskirynekwegla.pl/ (accessed on 25 August 2022).
19. Witucki, M.; Fedorczuk, M. *Prognozowane Zmiany na Rynku Pracy Wywołane Transformacją Energetyczną*; Conference Lewiatan: Warszawa, Poland, 2021; pp. 14–31. Available online: https://lewiatan.org/wp-content/uploads/2022/01/rynek_pracy_transformacja_10122021.pdf (accessed on 17 February 2022).
20. Bacon, R.; Masami, K. *Issues in Estimating the Employment Generated by Energy Sector Activities*; World Bank: Washingotn, DC, USA, 2011; pp. 1–80. Available online: https://openknowledge.worldbank.org/handle/10986/16969 (accessed on 30 March 2022).
21. Wasiuta, A. Labor market in Poland in the context of renewable energy sector development. *Ekon. Środowisko* **2018**, *1*, 198–207.
22. Ustawa z Dnia 20 Maja 2016 r. o Inwestycjach w Zakresie Elektrowni Wiatrowych. Dz.U. 2016, poz. 961. Internetowy System Aktów Prawnych. 2016. Available online: https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20160000961/U/D20160961Lj.pdf (accessed on 12 June 2022).
23. Martinez-Rodriguez, M.C.; Vera-Martinez, M.C. The clean energy economy: The labour market. Case study: Solae Energy. *Rev. Espac.* **2020**, *41*, 336–350. [CrossRef]
24. Instytut Badań Edukacyjnych. *Sektorowa Rama Kwalifikacji dla Energetyki (SRKE)*; Drzymulska-Derda, M., Panowicz, M., Żurawski, A., Eds.; Instytut Badań Edukacyjnych: Warsaw, Poland, 2020; pp. 1–64.
25. Shatilova, O.; Sobolieva, T.; Vostryakov, O. Gender equality in the energy sector: Analysis and empowerment. *Polityka Energetyczna Energy Policy J.* **2021**, *24*, 19–42. [CrossRef]

26. Bednarczyk, Z.; Kołos, N.; Nosarzewski, K.; Jagaciak, M.; Macander, Ł. Kompetencje, jakich nie było. Kompetencje przyszłości na mazowieckim rynku pracy w perspektywie do 2040 roku. *Wojewódzki Urząd Pr.* 2019, pp. 1–68. Available online: https://4cf.pl/wp-content/uploads/pdf/4CF_wup.pdf (accessed on 17 February 2022).
27. Lu, H.; Ma, X.; Ma, M. Impacts of the COVID-19 pandemic on the energy sector. *J. Zhejiang Univ. Sci. (Appl. Phys. Eng.)* **2021**, *22*, 941–956. [CrossRef]
28. Adamowicz, M. COVID-19 Pandemic as a Change Factor in the Labour Market in Poland. *Sustainability* **2022**, *14*, 9197. [CrossRef]
29. Eichhorst, W.; Marx, P.; Rinne, U. Manoeuvring Through the Crisis: Labour Market and Social Policies during the COVID-19 Pandemic. *Inter Econ.* **2020**, *55*, 375–380. [CrossRef] [PubMed]
30. Ciołek, D. Changes in the labour market during the COVID-19 pandemic and their spatial interactions—Evidence from monthly data for Polish LAU. *Geogr. Pol.* **2021**, *94*, 523–538. [CrossRef]

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Article

Household Ability of Expenditures on Electricity and Energy Resources in the Countries That Joined the EU after 2004

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Abstract: The purpose of the following article is to present the situation of the energy market from a household perspective between 2010 and 2020 in selected EU countries (the group of member states which joined EU after 2004). The selected countries when joining the EU had similar economic indicators and to some extent were similar in other macro-economic situations (personal income, unemployment rate, GDP level and annual growth). This article analyzes the past and current situation of the household ability expenditure on electricity and energy resources (petrol—eurosuper 95 and diesel and natural gas), taking into account price, tax conditions and the real possibility to purchase the analyzed energy sources (based on annual net salaries). The paper includes the conclusions and prospects for the future. The main objective of the study is to determine the ability amount of expenditure on electricity, natural gas and liquid fuels by household in the countries that joined the European Union after 2004. The specific objectives of the work include: the evolution of retail prices of energy sources in those countries and prices of electricity, natural gas and liquid fuels—petrol and diesel oil—in the research period from 2010 to 2020. The element that influences the final price, as assessed in this paper, is the share of taxes and compulsory charges imposed by the EU countries covered in this study. The result of the study presented inter alia that energy consumption structure did not change significantly, electricity prices were steadily growing in the countries under assessment, the use of liquid fuels—petrol and diesel oil—in the countries under study, grew over the study period. Furthermore, prices of fuel fluctuated over the period from 2010 to 2020 and during the COVID-19 pandemic, which broke out in March 2020, but did not cause any significant changes in the prices of energy carriers in the analyzed period, apart from the declines in the prices of eurosuper 95 and diesel.

Keywords: household; expenditure; electricity; gas; oil; diesel; taxation; EU

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1. Introduction

The European Community, established on 1 January 1958 and based on the Treaties of Rome, has been joined by various European countries since its beginning. The first stage of expansion took place in 1973 and included Denmark, Ireland and Great Britain. During the second stage, in 1981, Greece joined the European Community, and during the third stage, in 1986, Spain and Portugal joined. As soon as the existing Member States signed the Treaty on European Union, more countries joined. Austria, Finland and Sweden joined in 1995. In the history of the EU, there have been six stages of expansion, the largest of which took place on 1 May 2004, when ten countries joined the EU: Cyprus, the Czech Republic, Estonia, Lithuania, Latvia, Malta, Poland, Slovakia, Slovenia and Hungary. In 2007, the number of EU members increased to 27—Romania and Bulgaria also joined the Community, and in 2013, Croatia joined [1]. The countries that joined the European Union after 2004 are characterized by a lower level of consumption than the other members of the Community [2–5]. As in the other countries, the households incur expenditure for electricity and energy resources. In the literature on the subject, there is no assessment of the ability amount of expenditure on electricity and energy resources in thirteen counties of the European Union. This paper fills that research gap.

The research of many papers focuses on renewable energy sources which, due to climate policy, have become a priority in the last decade [6–11]. Many authors have also mentioned energy security because some countries do not produce liquid fuels and have to export them [10,12]. Scientists and consumers are worried about the dynamically changing prices of electricity [13–16] and liquid fuels [17–20]. The above is particularly important for the new members of the European Union as the households have much lower incomes than those in the states that joined the European Union before 2004 [21–24].

The main objective of the study is to determine the ability amount of expenditure on electricity, natural gas and liquid fuels by the households in the countries that joined the European Union after 2004. A novelty of this paper is undertaking the topic concerning the actual possibilities of purchasing the analyzed energy goods by citizens of countries that joined the EU after 2004. There are no similar studies in the literature and worldwide research, hence the authors believe that this study will fill a significant research gap.

The specific objectives of the work include: the evolution of retail prices of energy sources in those countries: prices of electricity, natural gas and liquid fuels—petrol and diesel oil—in the research period from 2010 to 2020. The element that influences the final price, assessed in this paper, is the share of taxes and compulsory charges imposed by the EU countries covered in this study. The process of the so-called harmonization of indirect taxes (value-added tax and excise duty) imposed on, inter alia, energy sources and carriers (mineral oil, gas, electricity, energy from alternative sources and aviation fuel) has been ongoing in the EU for years [25–31]. The basic structure of excise duty on mineral oil in the Community was established in 1992 [32,33]. As in the case of alcohol and tobacco products and contrary to the original plans for total harmonization, only minimum rates have been set. Thus, taxation in individual countries varies as it depends on the VAT rates adopted in a given country and on the level of excise duty which, however, should not be lower than the minimum rate agreed to by all members of the European Union [34].

The quantitative consumption of energy in households is reflected in the expenditure on individual energy carriers. In the study of household budgets under the assessed ability expenditure category, spending money on electricity, natural gas and liquid fuels was taken into account. An additional element of the analysis was to consider the level of inflation as well as wages and salaries in the countries covered in the study, which made it possible to determine the level and direction of price formation and the real ability to purchase individual energy carriers by the inhabitants of the countries under assessment.

2. Materials and Methods

The study covered the thirteen countries that joined the European Union after 2004. The period of the analysis described the years from 2010 to 2020. The source of the collected information was a review of the literature on the subject and Eurostat data. Descriptive, tabular and graphical methods, constant dynamic indicators and coefficient of variation were used for the analysis and presentation of the results. In the first stage of the study, the share of final energy consumption in the housing sector by EU Member State and by the source of consumption between 2010 and 2020 was analyzed. In the second stage, electricity prices (kWh) for households, including taxes and charges in the period from 2010 to 2020 were presented, in euros, as well as the prices without taxes and extra fees. This way, the net electricity prices and the percentage share of the fees and taxes were determined. Natural gas is one of the most important energy sources used in households. As in the case of energy, in the third stage of the study, the net prices of gas were analyzed, as well as the prices including the taxes and charges.

In the European Union, electric cars are most frequently registered in Germany, Great Britain and France [35]. A much smaller number of electric cars was registered in the thirteen countries under study. The differences in electromobility in individual EU countries result from the underdeveloped charging structure and lower household income in the thirteen countries under assessment [36–42]. However, and above all, higher prices of electric cars compared to those of internal combustion engine cars, plus lower subsidies for their purchase than in Western European countries, are the reasons for the low rate of growth in the number of electric cars in the states under assessment [43,44]. The above means the use of combustion engine cars to a greater extent in the analyzed countries, and, consequently, increased use of liquid fuels in the last decade of the 21st century. In the fourth stage of the study, the prices of these liquid fuels were analyzed: eurosuper 95 petrol and diesel oil (two most common ones used by individuals in the researched European Union member states). The strong fluctuations in world oil prices during the period under review may have had a negative impact on the economies of the importers of oil. The above contributed to an increase in production costs, and, consequently, to the increase in inflation. The level of consumption in the assessed countries is influenced by the level of wages and salaries which, in the case of the thirteen countries, did not exceed the average remuneration in the European Union. The authors of the paper have analyzed the ability to purchase individual energy carriers, taking into account annual wages and salaries in those countries. Descriptive, tabular and graphical techniques were used to present the data.

3. Results

According to Eurostat (2010–2020), energy from different sources (electricity, natural gas, heat pumps, fuel oils, coal and derivatives and from renewable sources) is used by EU residents mainly for space heating (63.6% of the EU average, see Table 1). Lighting and household appliances account for 14.1% of final energy consumption in households, while the share of energy used to heat water (for sanitary purposes) is slightly higher—14.8%. Cooking appliances use 6.1% of the energy consumed by the households, while space cooling equipment and other appliances consume 0.4% and 0.97%, respectively. Individual values vary; for example, those related to space cooling are much higher in southern European and Mediterranean countries (especially Malta with 11.83% share in final energy consumption). Consequently, space and water heating accounts for 78.4% of the final energy consumed by the households.

3.1. Electricity

Electricity is one of the most important energy sources used by households in the European Union [45]. Eurostat (2010–2020) estimates that electricity accounted for an average of 24.7% share in energy sources across all EU countries. The greatest percentage share was recorded in Malta—71.17%, and the smallest in Latvia—12.18%. The average share of electricity in the total energy consumption between 2010 and 2020 by households among the countries under study, that is, those that joined the EU after 2004, is presented in Figure 1.

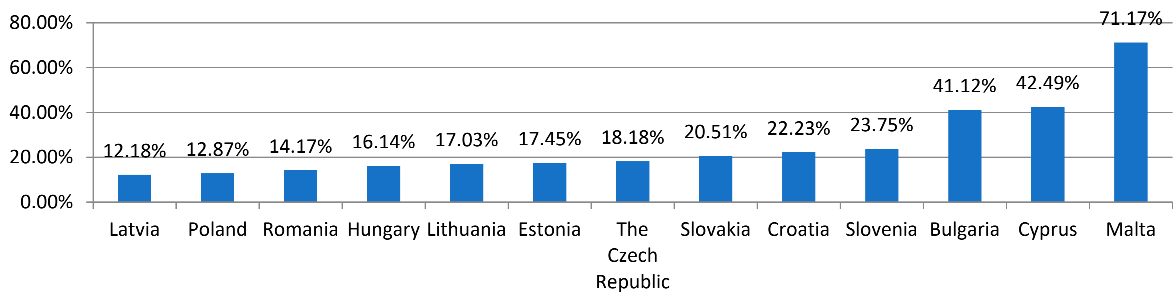

Figure 1. Share of electricity in total energy consumption by households (average between 2010 and 2020). Source: Own elaboration based on: [46].

Table 1. Share of final energy consumption in the residential sector by the EU Member State and by the source of consumption (average between 2010 and 2020).

Country	Space Heating	Space Cooling	Water Heating	Cooking Share	Lightning	Other
European Union—27 countries (from 2020)	63.64%	0.40%	14.80%	6.10%	14.10%	0.97%
Euro area—19 countries (from 2015)	64.32%	0.34%	14.07%	6.10%	14.51%	0.65%
Bulgaria	53.52%	0.43%	17.50%	7.98%	20.57%	0.70%
The Czech Republic	68.45%	0.07%	16.69%	6.31%	6.94%	1.54%
Estonia	72.47%	0.40%	11.83%	4.77%	10.93%	1.00%
Croatia	68.38%	1.67%	10.34%	6.81%	12.80%	1.00%
Cyprus	36.11%	10.83%	22.83%	7.47%	21.00%	1.76%
Latvia	65.76%	0.40%	18.32%	7.12%	8.19%	0.61%
Lithuania	70.36%	0.50%	8.87%	6.52%	14.25%	0.90%
Hungary	72.71%	0.15%	12.56%	4.72%	9.86%	0.70%
Malta	17.18%	11.83%	26.66%	15.06%	27.57%	1.70%
Poland	65.37%	0.40%	16.39%	8.28%	9.97%	0.90%
Romania	63.26%	0.32%	13.42%	9.55%	13.45%	0.50%
Slovenia	66.00%	0.49%	15.42%	3.80%	14.29%	0.30%
Slovakia	68.99%	0.14%	13.81%	5.28%	11.76%	0.02%

Source: Own elaboration based on: [46].

Depending on the country and, above all, the region, as well as the availability of collective energy sources (heat and power plants, municipal boiler houses or boiler rooms located in a specific housing estate or in a common space of a specific housing community), electricity is used for various purposes (heating or cooling households, power supply for the kitchen, lighting, other household appliances and audio/video devices) [47–49].

An important factor related to a household budget and ability expenditure on energy carriers is the purchase cost. Table 2 presents a summary of the costs of purchasing electricity by households in the period from 2010 to 2020 (two-year data presentation interval), taking into account taxes (VAT and excise duty) and other fees (including pro-environmental fees and charges introduced by individual EU countries) [50]. Based on the summary, the average purchase price of a kilowatt-hour in all EU countries has increased by EUR 0.05 over 10 years. In the assessed countries, the greatest increase was recorded in Latvia—EUR 0.08. In addition, a stable situation was noticed in Poland, Lithuania and Bulgaria (slight fluctuations in price), whereas the largest decrease in price was in Hungary (in the period from 2010 to 2020, the prices for a kilowatt-hour fell by EUR 0.07). In 2020, the lowest gross purchase price of electricity was recorded in Bulgaria and Hungary (EUR 0.10 per kWh), whereas the highest price was noticed in the Czech Republic (EUR 0.24 per kWh).

Apart from the costs of producing and transmitting electricity (the margins of the producer, seller and possible intermediary), the cost of purchasing electricity is affected by taxes and compulsory levies imposed by individual states [13]. It should be noted that energy carriers are subject to obligatory VAT and excise duty in the EU, and the tax rates (VAT and excise duty) in individual countries vary [52,53].

When analyzing the purchase prices of electricity excluding obligatory fiscal levies, it can be noticed that the average price of kWh in all EU countries was EUR 0.15 in 2020, compared to EUR 0.24 of the price, including taxes (see Table 3). At this point, it should be noted that in the EU countries, the share of taxes and fees in one kWh of the gross final price is 35.6%, on average. Having analyzed the net prices in the countries under study, in

2020, the lowest price was recorded in Hungary—EUR 0.0801, whereas the highest price was recorded in the Czech Republic—EUR 0.18. When analyzing the prices of electricity, we have not noted a significant change caused by the COVID-19 pandemic. Therefore, it did not have an impact on the final price of the electricity.

Table 2. Electricity prices (kWh) for households, including taxes and levies in the period from 2010 to 2020—prices in euros.

	European Union—27 Countries (from 2020)	Bulgaria	The Czech Republic	Estonia	Croatia	Cyprus	Latvia	Lithuania	Hungary	Malta	Poland	Romania	Slovenia	Slovakia
2010	0.19	0.08	0.21	0.10	0.11	0.20	0.10	0.12	0.17	0.19	0.15	0.11	0.17	0.18
2012	0.21	0.10	0.22	0.11	0.15	0.29	0.12	0.13	0.17	0.19	0.16	0.11	0.18	0.20
2014	0.23	0.09	0.18	0.14	0.14	0.23	0.12	0.13	0.12	0.14	0.15	0.13	0.19	0.17
2016	0.23	0.09	0.19	0.13	0.14	0.16	0.17	0.12	0.12	0.15	0.14	0.13	0.20	0.18
2018	0.24	0.10	0.21	0.15	0.14	0.23	0.16	0.11	0.11	0.15	0.15	0.13	0.20	0.17
2020	0.24	0.10	0.24	0.14	0.14	0.18	0.18	0.13	0.10	0.15	0.16	0.15	0.21	0.19

Source: Own elaboration based on: [51].

Table 3. Electricity prices (kWh) for households, excluding taxes and levies in the period from 2010 to 2020—prices in euros.

	European Union—27 Countries (from 2020)	Bulgaria	The Czech Republic	Estonia	Croatia	Cyprus	Latvia	Lithuania	Hungary	Malta	Poland	Romania	Slovenia	Slovakia
2010	0.14	0.07	0.17	0.07	0.09	0.17	0.10	0.10	0.13	0.18	0.12	0.09	0.12	0.16
2012	0.15	0.08	0.18	0.08	0.12	0.24	0.08	0.11	0.13	0.19	0.12	0.08	0.13	0.16
2014	0.15	0.08	0.15	0.10	0.11	0.19	0.07	0.09	0.09	0.14	0.12	0.09	0.13	0.14
2016	0.15	0.08	0.16	0.10	0.11	0.13	0.11	0.08	0.09	0.14	0.11	0.09	0.13	0.15
2018	0.16	0.08	0.17	0.11	0.11	0.19	0.11	0.08	0.09	0.14	0.10	0.10	0.13	0.10
2020	0.16	0.09	0.18	0.11	0.11	0.13	0.12	0.10	0.08	0.14	0.10	0.11	0.14	0.13

Source: Own elaboration based on: [51].

It should be noted that the greatest difference between the net purchase price of electricity and the gross price, and thus the share of taxes in the total price, was recorded in Slovenia and Poland (35%) in 2020, and the smallest difference was in Malta (5.7%) as presented in Table 4. Moreover, it should be noted that the taxation on electricity has increased over the past decade in all countries. The highest change was noted in Latvia, from 4.7% in 2010 to 31.7% in 2020. The average for the entire EU was 35.59% in 2020. The average share of tax in the gross price of electricity between 2010 and 2020 is presented in Figure 2.

Table 4. Share of taxes in electricity purchase prices for 1 kWh in 2020.

	European Union—27 Countries (from 2020)	Bulgaria	The Czech Republic	Estonia	Croatia	Cyprus	Latvia	Lithuania	Hungary	Malta	Poland	Romania	Slovenia	Slovakia
2010	27.8%	13.5%	18.6%	27.5%	17.2%	16.1%	4.7%	14.7%	22.5%	3.6%	22.1%	23.2%	28.6%	14.1%
2012	28.9%	20.7%	18.4%	26.3%	20.6%	17.2%	30.9%	17.9%	24.4%	2.7%	23.0%	29.8%	25.3%	20.2%
2014	34.1%	16.6%	16.6%	28.1%	21.6%	17.2%	39.2%	30.8%	21.8%	1.7%	22.6%	27.5%	31.8%	17.6%
2016	35.6%	12.1%	18.6%	24.2%	21.4%	20.2%	34.9%	30.6%	23.3%	7.5%	20.1%	29.9%	36.4%	19.0%
2018	33.8%	16.4%	17.5%	28.0%	20.1%	19.6%	32.4%	28.6%	18.3%	6.7%	35.6%	25.0%	34.8%	39.2%
2020	35.6%	15.0%	26.6%	24.1%	21.4%	28.1%	31.7%	23.9%	19.9%	5.7%	35.1%	30.3%	35.5%	31.9%

Source: Own elaboration based on: [51].

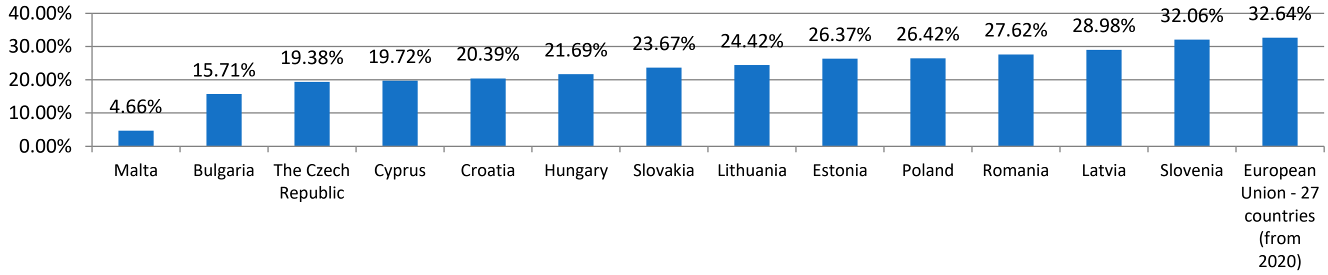

Figure 2. Average share of taxes in gross price of electricity in selected EU countries between 2010 and 2020 (average between 2010 and 2020). Source: Own elaboration based on: [51].

According to the data presented in Figure 2, Malta had the lowest share of taxes in gross price of electricity throughout the period from 2010 to 2020, whereas the highest level was noticed in Slovenia—32.06%. However, all analyzed countries had lower levels of taxation than the average from all EU countries, which basically means that the level of imposed taxes is lower in the countries than joined EU after 2004 than in those which have been EU members for a longer period of time.

3.2. Natural Gas

Natural gas is one of the basic energy sources for households [54,55]. In all EU countries, it accounted for 32.1% share of all energy sources, on average. Therefore, it should be noted that natural gas is a more popular source of energy than electricity in the area under study, on average, since electricity accounts for 24.7% of the EU average. As in the case of electricity, the share of an energy carrier in the overall energy mix depends primarily on the geographical location. Moreover, not every country has the same level of reserves of natural gas or is able to import it (access to gas pipelines or infrastructure necessary to handle liquefied gas, e.g., in seaports). Two island countries, Cyprus and Malta, did not record gas consumption by households at all (thus they are not included in the assessment in this part of the article) [56]. Among the countries under study, the greatest share of consumption of natural gas was recorded in Slovakia—51.4%, whereas the lowest share, among the countries using that type of fuel, was noticed in Bulgaria—2.58%. The share of natural gas in the total energy consumption by households among the countries under study, that is, those that joined the EU after 2004, is presented in Figure 3.

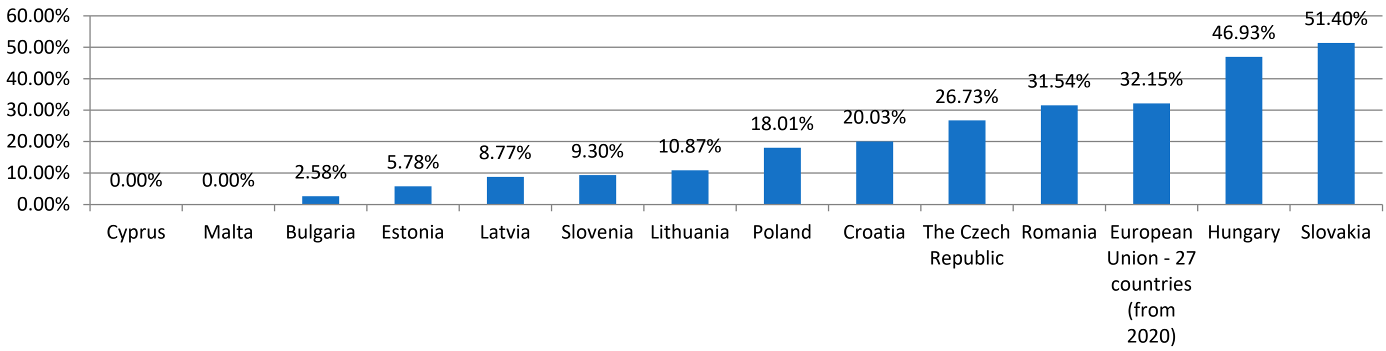

Figure 3. Share of natural gas in the total energy consumption of households in the selected EU countries (average between 2010 and 2020). Source: Own elaboration based on: [46].

During the period under review, there was a clear difference in gas prices between the countries. In 2010, the lowest prices of gas were recorded in Romania (approximately EUR 0.028 gross for the equivalent of 1 kWh), whereas the highest prices were recorded in Slovakia (EUR 0.097 gross for the equivalent of 1 kWh). During the same period of time, the EU average was EUR 0.095. In the analyzed period, that is, the period from

2020 to 2010, in the EU, there was an overall increase in price—from EUR 0.095 to EUR 0.105 (an increase of 10.48%). The prices fluctuated in the states under assessment. In six countries, the prices dropped: Estonia −6.62%, Bulgaria −11.38%, Slovenia −21.09%, Poland −21.58%, Lithuania −39.48% and Hungary −49.01%. In five countries, the prices of natural gas increased: Romania +16.42%, Croatia +25%, Slovakia +26.52%, the Czech Republic +33.87% and Latvia +47.36%.

Similar to electricity, the tables with differences between the net and gross price are presented (Tables 5 and 6). As presented in all countries, the taxes on natural gas influence the final price for individual consumers. Unlike with electricity, the share of taxes in natural gas is lower.

Table 5. Prices of natural gas (per kWh) for households (consuming between 20 and 200 GJ per year) including taxes and levies for the period from 2010 to 2020—prices in euros.

TIME	European Union—27 Countries (from 2020)	Bulgaria	The Czech Republic	Estonia	Croatia	Latvia	Lithuania	Hungary	Poland	Romania	Slovenia	Slovakia
2010	0.10	0.04	0.08	0.05	0.04	0.07	0.07	0.06	0.06	0.03	0.07	0.10
2012	0.11	0.06	0.10	0.06	0.05	0.08	0.09	0.06	0.07	0.03	0.10	0.10
2014	0.11	0.05	0.09	0.06	0.05	0.07	0.08	0.04	0.07	0.03	0.07	0.10
2016	0.11	0.03	0.09	0.04	0.05	0.07	0.07	0.04	0.05	0.03	0.07	0.10
2018	0.12	0.05	0.11	0.05	0.05	0.07	0.07	0.04	0.05	0.04	0.06	0.11
2020	0.11	0.04	0.11	0.05	0.05	0.10	0.04	0.03	0.05	0.03	0.06	0.12

Source: Own elaboration based on: [51].

Table 6. Prices of natural gas (per kWh) for households (consuming between 20 and 200 GJ per year), excluding taxes and levies for the period from 2010 to 2020—prices in euros.

TIME	European Union—27 Countries (from 2020)	Bulgaria	The Czech Republic	Estonia	Croatia	Latvia	Lithuania	Hungary	Poland	Romania	Slovenia	Slovakia
2010	0.07	0.04	0.07	0.04	0.03	0.06	0.06	0.05	0.05	0.02	0.06	0.08
2012	0.09	0.05	0.08	0.05	0.04	0.07	0.07	0.04	0.06	0.02	0.08	0.08
2014	0.09	0.04	0.07	0.04	0.04	0.06	0.06	0.03	0.05	0.02	0.05	0.09
2016	0.08	0.03	0.08	0.03	0.04	0.05	0.06	0.03	0.04	0.02	0.05	0.08
2018	0.09	0.04	0.09	0.04	0.04	0.06	0.05	0.03	0.04	0.03	0.04	0.09
2020	0.08	0.03	0.09	0.04	0.04	0.08	0.03	0.02	0.04	0.03	0.04	0.10

Source: Own elaboration based on: [51].

The share of taxes varied widely across the countries, as presented in Table 7. We can observe that the lowest share of taxes in 2010 was noted in Latvia—9.2%, whereas the highest in Romania 47.86%. In 2020, the share of taxes in the gross price of natural gas was the lowest in Romania and the highest in Slovenia. It is worth noting that in case of Romania, the share of taxation has significantly decreased by 68%.

The average share of taxes in analyzed countries between 2010 and 2020 is presented in Figure 4. During that period, the highest level was noticed in Romania (37.81% on average) and the lowest in Slovakia (16.53%).

Based on Figure 4, we can come to the conclusion than in most analyzed countries, i.e., nine, the average share of taxes in the gross price of natural gas for households was lower than the total average for all EU member states. Only two countries (Slovenia and Romania) had a higher level of taxation than the EU average; however, as mentioned before, Romania had significantly decreased the value between 2010 and 2020.

3.3. Liquid Fuels (Petrol and Diesel Oil)

Liquid fuels such as petrol and diesel are among the significant expenses incurred by households. It should be noted that in the majority of the EU countries, the price of fuel depends mainly on the price of the basic raw material, which is crude oil, and taxes which, in most cases, account for over 50% of the final gross price. It should also be noted that as long as the number of electric cars does not increase, the price of petrol and diesel oil (in some countries, also alternative fuels such as LPG and more and more popular CNG) will be the main element of the transport expenditure catalogue (see Table 8.). Although the number of electric vehicles continues to grow, the global share of the sale of electric vehicles versus the total sale of new vehicles was only 4.61% in 2020 [57,58]. When it comes to analyzed countries, the number of newly registered electric vehicles did not achieve a significant number. The volume of the newly registered cars in selected countries (not all data is available) is presented in Figure 5.

Table 7. Share of taxes in natural gas for households (consuming between 20 and 200 GJ per year) for the period from 2010 to 2020.

TIME	European Union—27 Countries (from 2020)	Bulgaria	The Czech Republic	Estonia	Croatia	Latvia	Lithuania	Hungary	Poland	Romania	Slovenia	Slovakia
2010	23.10%	16.59%	16.62%	21.21%	18.95%	9.20%	17.27%	20.03%	18.06%	47.86%	22.70%	15.96%
2012	22.76%	16.61%	16.61%	20.35%	20.09%	19.50%	17.40%	22.87%	18.72%	46.91%	21.38%	16.67%
2014	23.28%	16.63%	17.31%	20.44%	19.93%	19.62%	17.35%	21.22%	18.70%	51.71%	25.94%	16.59%
2016	24.74%	16.67%	17.29%	24.93%	19.87%	20.21%	17.35%	21.33%	18.79%	48.32%	27.74%	16.73%
2018	24.37%	16.63%	17.38%	26.32%	20.04%	19.72%	20.66%	21.33%	18.98%	16.10%	28.97%	16.64%
2020	23.69%	16.84%	17.50%	24.58%	20.00%	19.14%	23.02%	21.10%	19.62%	15.95%	29.45%	16.63%

Source: Own elaboration based on: [51].

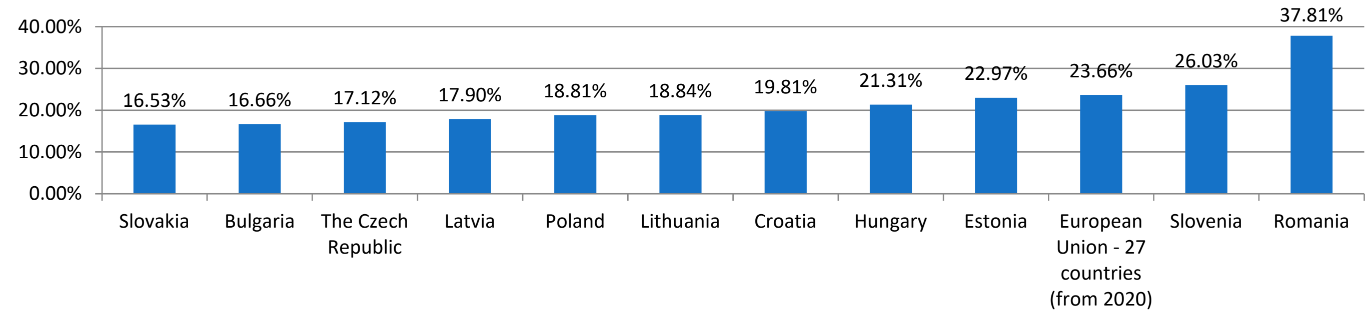

Figure 4. Average share of taxes in gross price of natural gas for households (consuming between 20 and 200 GJ per year) in selected EU countries (average between 2010 and 2020). Source: Own elaboration based on: [51].

Table 8. Number of the sale of electric vehicles in the sale of new vehicles worldwide in the period from 2010 to 2020.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
The Czech Republic	NA	NA	NA	237	417	713	974	1525	2482	8180	7103
Estonia	NA	NA	600	708	1067	1116	1156	1191	1254	1382	2147
Croatia	NA	NA	NA	NA	NA	163	233	285	461	725	987
Latvia	NA	NA	10	15	188	211	241	312	442	658	1247
Lithuania	NA	NA	NA	NA	70	169	358	619	965	1395	1696
Hungary	NA	NA	90	110	175	342	758	1996	3839	6595	6101
Romania	NA	NA	1000	2042	2737	3863	6348	9947	1103	2798	2007
Slovenia	NA	NA	NA	NA	133	288	457	779	1308	1998	1926

Source: [59].

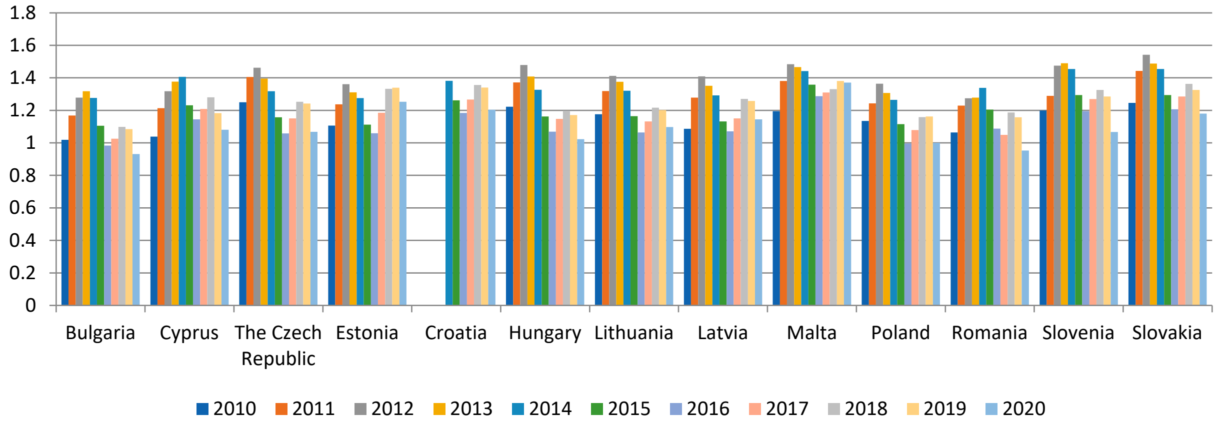

Figure 5. Average annual gross purchase price of 1 L of eurosuper 95 petrol in selected EU countries, in the period from 2010 to 2020 (prices in euros). Source: Own elaboration based on: [60].

Hence, taking into account the fact that petrol and diesel oil will remain the main source of power supply for passenger vehicles in the coming years, it is necessary to analyze the price formation in the selected EU countries.

When analyzing the changes in price over the decade, it should be noted that, in 2010, the lowest price of petrol was recorded in Bulgaria—EUR 1.01 per liter, whereas the commodity was the most expensive in the Czech Republic—EUR 1.25 per liter (see Figure 6). It should be noted that the price of petrol has fluctuated over the 10-year period. There was a general rise in price until 2012; then, the prices fell before rising again. A clear reduction in the price of petrol can be noticed by comparing the years 2019 and 2020. During that period, due to the outbreak of the COVID-19 pandemic, most EU countries introduced numerous sanitary restrictions, which consequently led to a reduction in economic activity and to a significant reduction in demand for liquid fuels (in 2020, record low oil prices were also seen in world markets).

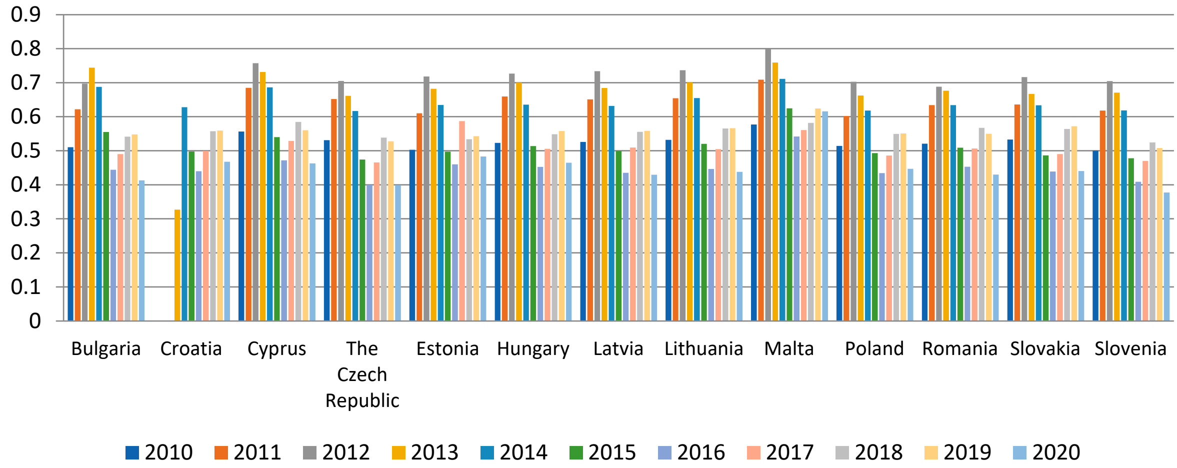

Figure 6. Average annual net purchase price of 1 L of eurosuper 95 petrol in selected EU countries, in the period from 2010 to 2020 (prices in euros). Source: Own elaboration based on: [60].

Table 9 presents the share of taxation in eurosuper 95. As we can see, the level of taxation in petrol is generally much higher than in electricity and natural gas. It is mainly caused by the fact that petrol, including diesel, is generally imposed with the highest possible VAT rate, as well as the fact that higher excise tax may be included. The detailed data is presented below.

Table 9. Share of taxes in eurosuper 95 price in selected EU countries between 2010 and 2020.

	Bulgaria	Croatia	Cyprus	The Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Romania	Slovakia	Slovenia
2010	48.34%	No data	44.99%	55.56%	52.62%	54.58%	50.33%	52.58%	50.19%	53.11%	49.72%	56.59%	55.17%
2012	44.51%	No data	44.70%	52.19%	47.60%	50.55%	48.65%	48.43%	47.19%	48.90%	46.54%	54.36%	53.61%
2014	44.83%	54.58%	49.03%	52.90%	49.11%	51.15%	50.24%	49.71%	49.45%	50.21%	49.86%	55.80%	56.23%
2016	53.54%	61.69%	57.52%	60.88%	53.50%	56.80%	57.54%	56.70%	57.55%	55.68%	55.02%	62.74%	64.37%
2018	50.09%	58.57%	53.48%	57.25%	59.69%	53.28%	55.95%	53.20%	55.51%	52.60%	52.35%	57.73%	60.44%
2020	55.66%	61.14%	57.16%	62.63%	61.44%	54.53%	62.48%	60.09%	55.07%	55.31%	54.85%	62.69%	64.66%

Source: Own elaboration based on: [60].

When analyzing the share of taxes in the final price of petrol, we can see that, generally, it increases year by year (see Table 9 and Figure 7). In 2010, the lowest number was in Cyprus, with a 44.99% tax share, whereas the highest was in Slovakia—56.59%. When it comes to 2020, the lowest tax share in the gross price was in Hungary—54.53%, and the highest in Slovenia—64.66%. The share of taxes in the final price is much higher than that of the price of electricity or natural gas.

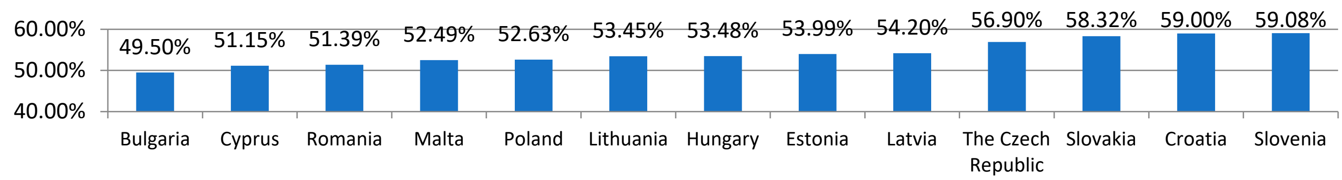

Figure 7. Average share of taxes in gross price of eurosuper 95 in selected EU countries between 2010 and 2020. Source: Own elaboration based on: [60].

When it comes the period from 2010 to 2020, the following changes in the prices of petrol over the 10 years can be noticed (see Figure 8). As we can see, four countries recorded an increase in petrol prices, whereas nine recorded a decrease. It was caused mainly by the COVID-19 pandemic, as the demand for petrol decreased dramatically in the first two quarters of 2020.

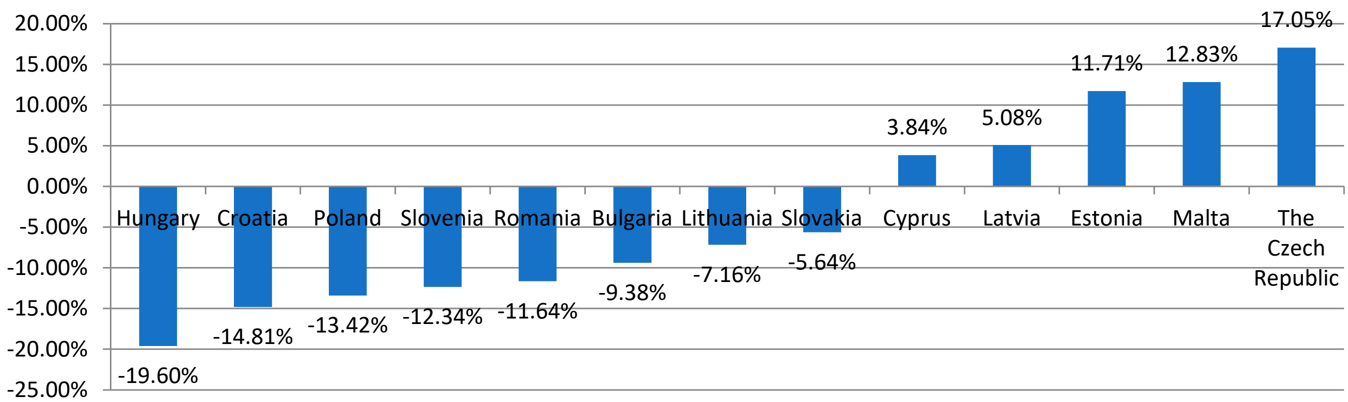

Figure 8. Average change in gross prices of eurosuper 95 in selected EU countries between 2010 and 2020. Source: Own elaboration based on: [60].

The other popular fuel in EU is diesel. Diesel prices are generally comparable to eurosuper 95. The possible difference in price between countries may be caused by the individual demand and supply (some EU countries are becoming stricter when it comes to diesel fuel and do not allow some vehicles to operate in city centers) as well as the various approaches towards taxation (Figure 9).

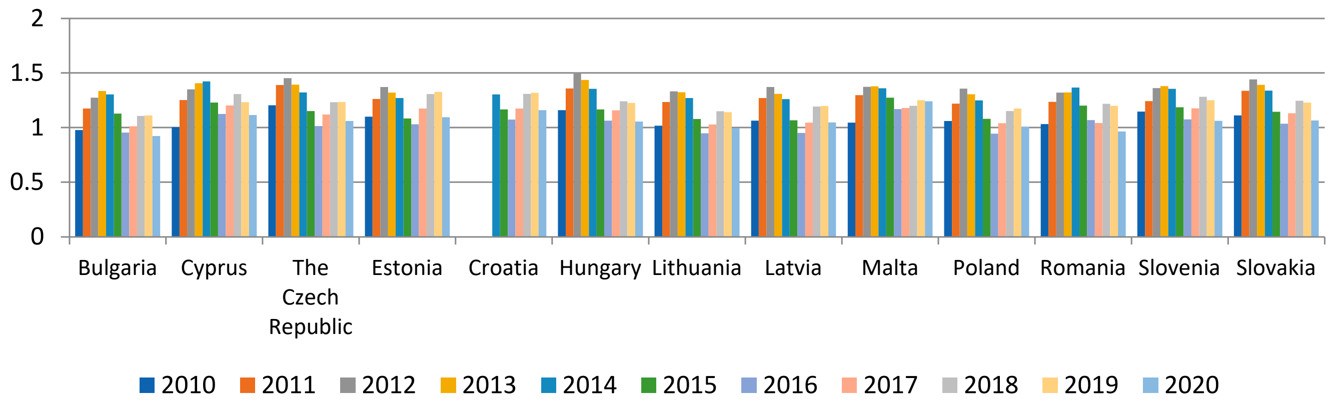

Figure 9. Average annual gross purchase price of 1 L of diesel oil in selected EU countries, in the period from 2010 to 2020. (Prices in euros). Source: Own elaboration based on: [60].

Considering diesel prices, as in the case of petrol, a change in price over the years can be observed, in similar periods. In 2010, the cheapest diesel oil was recorded in Bulgaria—EUR 0.98 per liter, and the most expensive in the Czech Republic—EUR 1.23 per liter. However, in 2020, the lowest price was in Bulgaria— EUR 0.92 per liter, whereas the highest was in Malta—EUR 1.24 per liter.

When analyzing the share of taxes in both petrol and diesel, we can note that the share is much higher than that of electricity or natural gas (Figure 10 and Table 10). In terms of diesel, the highest share of taxes in 2010 was in Czech Republic—50.42%, whereas the lowest was in Cyprus— 41.52%. In 2020, the highest taxation was in Slovenia—62.35%, whereas the lowest was in Poland—50.68%.

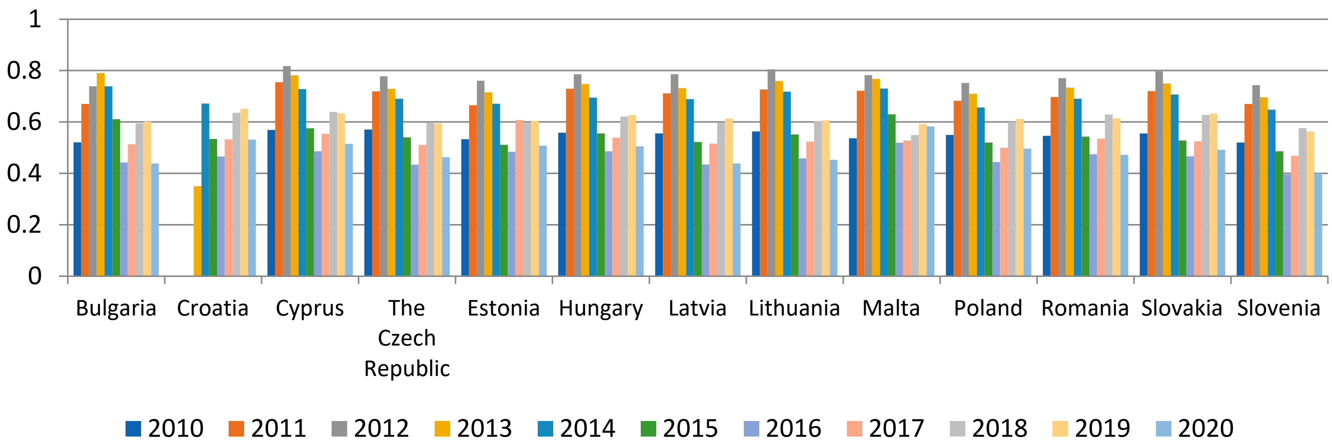

Figure 10. Average annual net purchase price of 1 L of diesel oil in selected EU countries, in the period from 2010 to 2020 (prices in euros). Source: Own elaboration based on: [60].

Table 10. Share of taxes in diesel price.

	Bulgaria	Croatia	Cyprus	The Czech Republic	Estonia	Hungary	Latvia	Lithuania	Malta	Poland	Romania	Slovakia	Slovenia
2010	44.84%	No data	41.52%	50.42%	49.44%	49.07%	45.89%	42.89%	46.51%	46.10%	45.39%	48.10%	50.35%
2012	41.37%	No data	41.96%	47.09%	45.18%	47.86%	43.39%	41.11%	43.64%	45.08%	43.08%	45.36%	47.46%
2014	44.57%	51.36%	51.00%	50.43%	50.02%	50.56%	48.17%	46.15%	48.45%	49.62%	52.14%	50.53%	55.62%
2016	51.41%	55.63%	55.36%	55.79%	50.70%	53.92%	52.48%	50.33%	55.45%	52.47%	52.15%	54.24%	61.66%
2018	46.04%	51.03%	49.83%	51.70%	54.42%	49.38%	49.34%	47.18%	53.50%	47.91%	48.55%	49.05%	55.00%
2020	52.43%	54.12%	53.82%	56.33%	53.64%	52.08%	58.10%	54.54%	53.04%	50.68%	51.02%	53.82%	62.35%

Source: Own elaboration based on: [60].

Over the period from 2010 to 2020, the average share of taxation in the gross price of diesel was the highest in Slovenia, exceeding 55%, whereas the lowest was in Bulgaria—almost 47%. It had impact on the final price of diesel petrol in Bulgaria, as it remained the cheapest in that country; however, Slovenia, despite having the highest taxation, was not noted as the highest price, on average (see Figure 11).

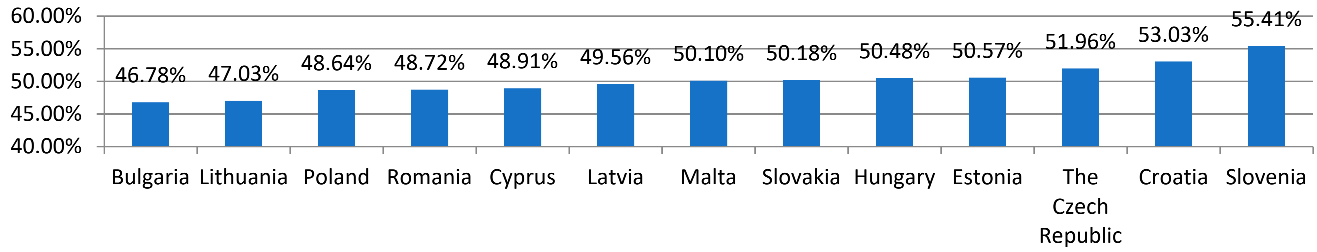

Figure 11. Average share of taxes in gross price of diesel in selected EU countries between 2010 and 2020. Source: Own elaboration based on: [60].

The below shows the following price changes, taking place from 2010 to 2020, as the years of comparison. As noted in the most analyzed countries, the average price between 2010 and 2020 decreased. The most significant decrease was noted in the Czech Republic. Only two countries noted the price increase, i.e., Cyprus and Malta. This is caused mainly by the lockdowns introduced to almost all European countries and the lowering demand for both petrol and diesel in 2020 (see Figure 12).

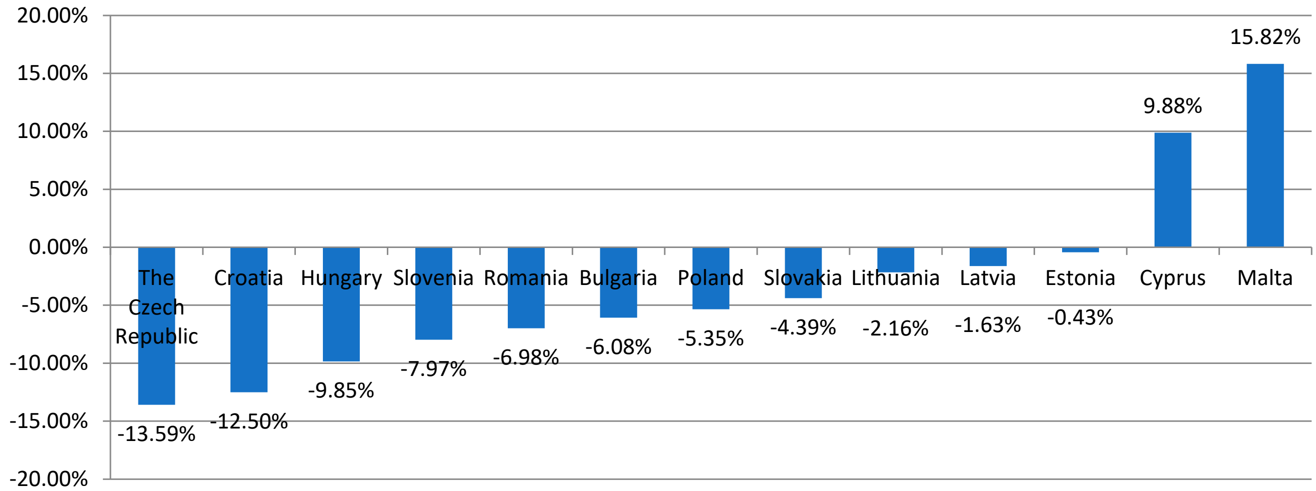

Figure 12. Average change in gross prices of diesel in selected EU countries between 2010 and 2020. Source: Own elaboration based on: [60].

3.4. Salaries and Wages

An important factor that influences the level of consumption is the level of wages and salaries of the residents. In the countries that joined the EU after 2004, the level of wages and salaries was significantly lower than those of the states that joined the European Union earlier (see Figure 13) [61–63]. Moreover, none of the analyzed countries reached the EU average; therefore, all of those countries are lower than the EU's average level of wages and salaries. It should be noted that the highest wages and salaries, among the countries under assessment, were recorded in Malta (slightly over EUR 50,000 per year), whereas the lowest were in Bulgaria (EUR 18,000 per year, on average). The average annual remuneration for all EU countries was EUR 70,000, in 2020. In all the countries, average wages and salaries increased over the period from 2010 to 2020.

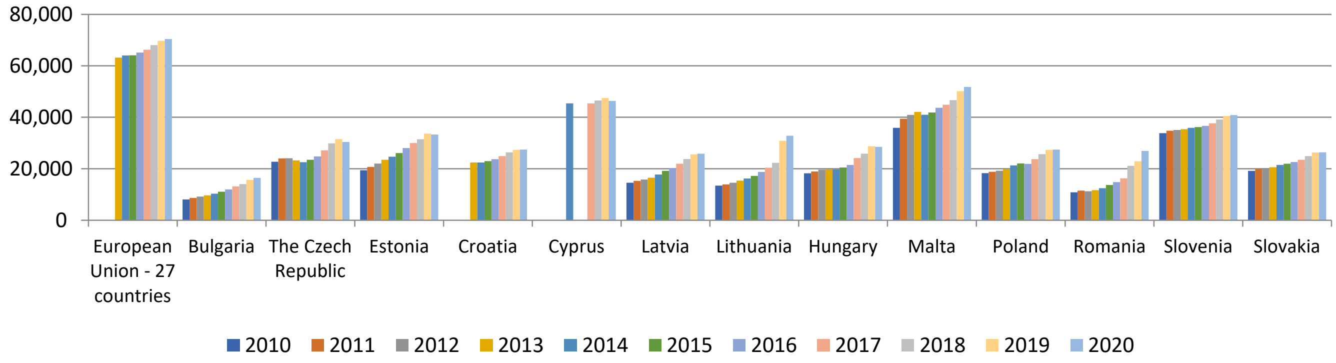

Figure 13. Annual average earnings for a single-person household in selected EU countries, in the period from 2010 to 2020, including taxes and social security contributions (in euros). Source: [64].

Considering the issues that are the subject of this study, it is important to determine the potential level and ability to purchase energy and its carriers by households. For that purpose, to conduct the analysis, the level of net wages and salaries should be taken into account. It should be noted that the difference between the gross and net amount results, to a large extent, from so-called labor costs.

Labor costs are the expenses incurred by an economic unit related to recruiting an employee. In the literature on the subject, the costs are often referred to as employer's costs or employment costs, and are often considered to be one of the factors that make up the price of an offered product or service (see Figure 14). Thus, labor costs are defined as the value of labor used to provide services or to manufacture certain goods.

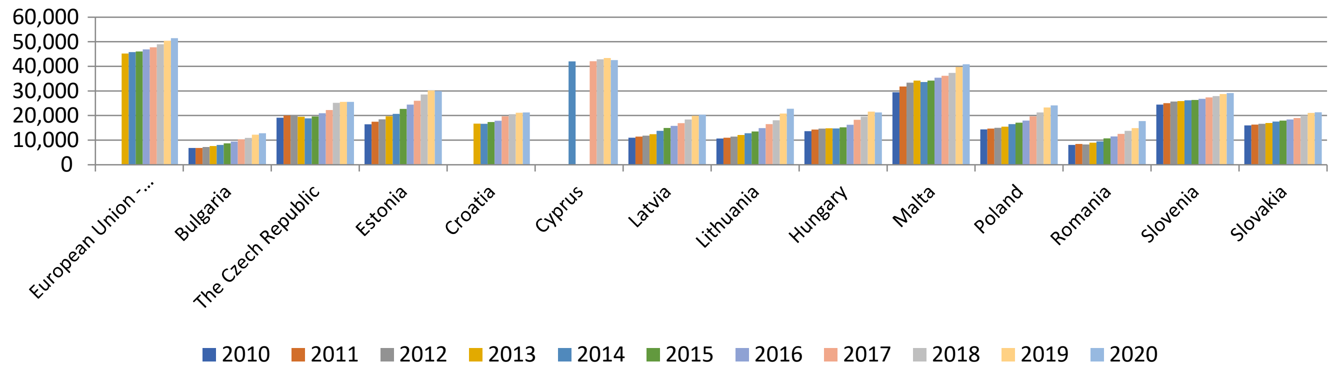

Figure 14. Annual average earnings of a single-person household in selected EU countries, in the period from 2010 to 2020, excluding taxes and social security contributions (in euros). Source: [64].

Taking into consideration the so-called labor components, they can be divided into wage components, that is, the expenses directly related to the remuneration of an employee, and non-wage components. For the purpose of international comparisons, Eurostat narrows down labor costs by including wage and salary costs into wage components, and employers' social security contributions are considered to be non-wage components (Eurostat, 2010–2020) presented in Figure 15.

Across the EU, the share of taxes and compulsory contributions in gross remuneration was nearly 27%, on average. The lowest ratio was recorded in Cyprus—8.05% and the greatest in Romania—over 32%.

3.5. Inflation

The last factor under assessment that influences the level of consumption is the overall changes in price, as measured by inflation. That indicator varied widely across the analyzed countries during the period under review. In some of the countries (Bulgaria, Estonia, Croatia, Cyprus, Latvia, Lithuania, Poland, Romania, Slovenia and Slovakia), medium-term (up to 3 years) deflation was also recorded (see Figure 16).

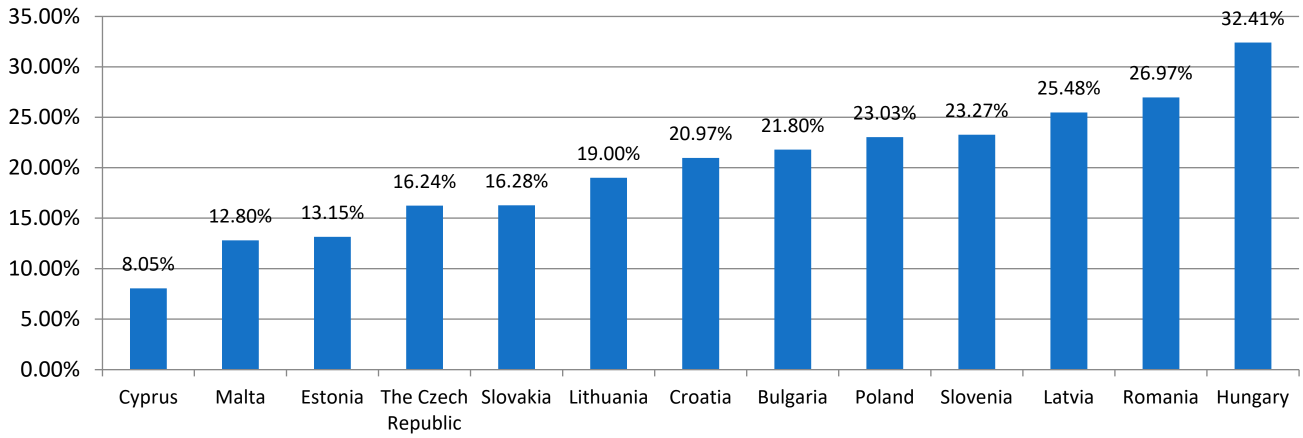

Figure 15. Average tax and insurance share in gross remuneration in selected EU countries between 2010 and 2020. Source: [64].

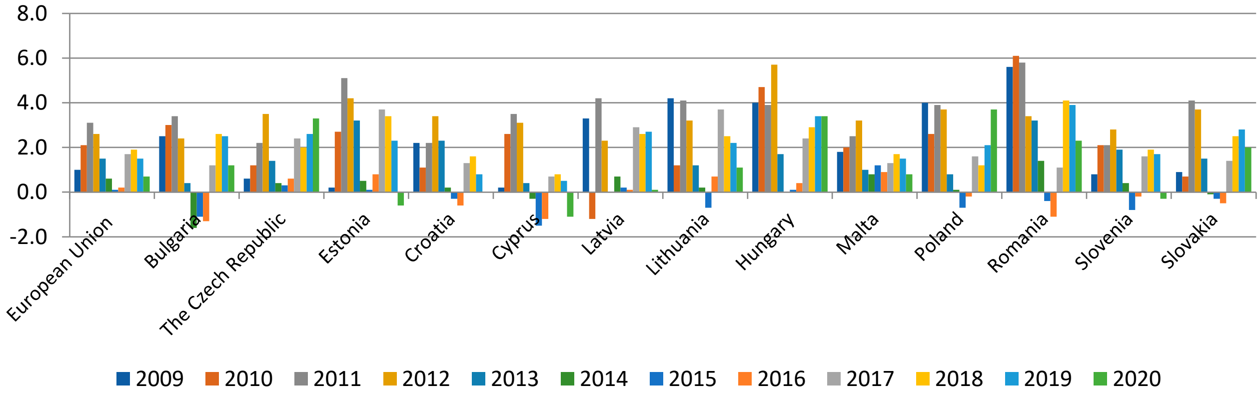

Figure 16. Annual average HICP inflation in selected EU countries, in the period from 2010 to 2020 (data in %). Source: [65].

The strong fluctuations in crude oil prices in the world markets, recorded in the second decade of the 21st century, may have serious negative consequences for the functioning of the economies of the countries that import significant amounts of that commodity. The impact of oil and fuel prices on inflation takes place through several channels. First, the prices of refinery products, as a group of goods in the consumption basket, are directly taken into account in the construction of the consumer price index. Second, crude oil and its derivatives are used in production processes in many industries and in transport. Therefore, an increase in their price contributes to an increase in production costs, which tends to increase inflation.

While analyzing the levels of inflation in individual countries, it is important to bear in mind that it is an imperfect measure, as it has to be compared with real purchasing power. Thus, in the next part of the study, that is, in Conclusions, indicators will be presented that describe the real purchasing power of residents of individual countries. We can observe that in the last 3–4 years of the analyzed period, the inflation rate has gradually grown.

When analyzing prices in nominal terms, it should not be forgotten that, given the changes in wages and salaries as well as inflation, such a study would, in principle, be flawed. It should be noted that the prices of individual goods and services may change; however, when earnings change, the increase or decrease in nominal terms may not be that significant.

3.6. Household Expenditure

For the comprehensive analysis of the prices of energy carriers (electricity, gas and liquid fuels) and earnings and inflation, the authors of the study presented a summary of the ability to purchase individual energy carriers for an average annual salary, and a comparison of the years between 2010 and 2020. The data in Table 11 shows the real purchase ability with regards to energy carriers, taking into account the change in nominal prices (gross values) and the average annual net remuneration.

Table 11. Ability to purchase individual energy carriers for an annual average net salary in selected countries in the period from 2010 to 2020.

	Electricity (kWh)			Natural Gas (kWh Equivalent)			Eurosuper 95 (Liter)			Diesel Oil (Liter)		
	2010	2020	Change	2010	2020	Change	2010	2020	Change	2010	2020	Change
Bulgaria	82,141.59	125,491.58	52.77%	161,947.39	342,585.29	111.50%	6709.90	13,759.49	105.00%	6987.45	13,897.08	99.00%
Cyprus	179,330.23	231,931.77	29.33%	NA	NA	NA	29,912.50	39,396.15	32.00%	29,550.85	38,189.36	29.00%
The Czech Republic	92,461.22	107,658.41	16.44%	240,818.39	240,129.92	−0.30%	15,296.75	23,903.11	56.00%	15,887.81	24,092.14	52.00%
Estonia	16,1401.27	210,305.34	30.30%	320,290.47	623,029.58	94.50%	14,879.47	23,864.01	60.00%	14,961.58	27,295.93	82.00%
Croatia	11,6478.01	151,935.36	30.44%	309,740.41	447,809.47	44.60%	12,034.64	17,669.83	47.00%	12,757.31	18,353.36	44.00%
Hungary	82,310.90	208,963.03	153.87%	226,354.97	689,985.06	204.80%	11,180.92	20,785.83	86.00%	11,791.30	20,133.61	71.00%
Lithuania	85,927.68	169,758.27	97.56%	154,520.17	546,320.38	253.60%	9053.83	20,760.29	129.00%	10,465.10	22,877.88	119.00%
Latvia	104,674.14	112,305.79	7.29%	165,457.77	208,518.63	26.00%	10,097.93	17,800.41	76.00%	10,311.52	19,461.38	89.00%
Malta	152,817.13	272,372.00	78.23%	NA	NA	NA	24,644.67	29,804.35	21.00%	28,193.54	32,926.98	17.00%
Poland	96,497.71	147,774.72	53.14%	239,953.34	514,848.4	114.60%	12,647.37	24,138.75	91.00%	13,534.35	23,993.75	77.00%
Romania	75,831.98	121,717.78	60.51%	287,078.21	543,996.32	89.50%	7558.09	18,616.28	146.00%	7788.01	18,381.27	136.00%
Slovenia	143,705.71	140,311.42	−2.36%	330,134.73	498,538.01	51.00%	20,375.64	27,278.46	34.00%	21,314.18	27,425.09	29.00%
Slovakia	86,884.19	109,494.36	26.02%	165,755.23	174,778.46	5.40%	12,835.49	18,090.03	41.00%	14,382.49	20,031.21	39.00%

For Cyprus and Croatia, the presented data is for 2014. Source: Own calculations and elaboration.

In the case of electricity, the largest increase in the ability to purchase that commodity for the average net remuneration was recorded in Hungary (+153.87%). In Slovenia, the buying power decreased by 2.36%. Having analyzed the absolute values, in 2010, the greatest amount of electricity could be purchased by the inhabitants of Cyprus (179,000 kWh), and the smallest amount by the residents of Romania (75,000 kWh). In 2020, the greatest amount of electricity could be purchased by the residents of Malta (272,000 kWh, an increase of 78.23% compared to 2010), whereas the smallest amount could be purchased by the residents of the Czech Republic (107,000 kWh, an increase of 16.44% compared to 2010).

With regards to natural gas, the greatest increase in the buying power was recorded in Lithuania (+ 253.6%), whereas in the Czech Republic, the purchase ability declined by 0.3%. In absolute terms, in 2010, the inhabitants of Slovenia were able to buy the largest amount of gas (330,000 kWh equivalent), whereas the smallest amount could be bought by the residents of Lithuania (154,000 for the equivalent of kWh). In 2020, the greatest amount of natural gas could be purchased by the residents of Hungary (689,000 for the equivalent of kWh, an increase of 204.8% compared to 2010), whereas the smallest amount could be purchased by the residents of Slovakia (174,000 for the equivalent of kWh, an increase of 2.9% compared to 2010). With regards to gas, the situation in Cyprus and Malta was not taken into account for the analysis, as the households did not use that raw material.

When it comes to the prices of liquid fuels, the increase in real purchase power is not as large as in the case of electricity and gas. The maximum increase was recorded for petrol—146% and for diesel oil—136%.

Having compared the ability to purchase petrol in relative values in the years 2010 and 2020, the largest increase was recorded in Romania (+146%), whereas the smallest was in Malta (+21%). Taking absolute values into account, in 2010, the residents of Bulgaria were able to purchase the smallest amount of petrol (6709 L), whereas the inhabitants of Cyprus, the largest amount (29,912 L). In 2020, the residents of Bulgaria were still able to buy the smallest amount of petrol (13,759 L, an increase of 105%), whereas the inhabitants of Cyprus were still able to purchase the largest amount of that commodity (39,396 L, an increase of 32%).

With regards to diesel oil, the greatest increase in purchase power was recorded in Romania (+136%), whereas the smallest was in Malta (+17%). In 2010, the residents of Bulgaria were able to buy the smallest amount of diesel oil (6.987 L), whereas the largest amount of that commodity could be purchased by the residents of Cyprus (38,189 L). In 2020, the inhabitants of Bulgaria were still able to buy the smallest amount of diesel oil (13,897 L, increase by 99%), whereas the residents of Cyprus were still able to purchase the largest amount of that commodity (38,189 L, increase by 29%).

4. Discussion

The authors proved that electricity prices in the countries that joined the European Union after 1 May 2004 grew in the analyzed period. In these countries, renewable sources of energy (RSE) were used to a smaller extent than in Western European countries, and energy prices were characterized by lower volatility [50,66–70]. The basic raw materials used to generate electricity in thirteen countries were coal, oil and gas, exported mainly from the Russian Federation [71]. Although the article does not discuss energy sources, the authors notice a growing need for a debate and research on this topic. This subject has been discussed in numerous studies, in which a detailed attempt was made to analyze energy sources and the importance of renewable sources (solar, hydro and wind energy) [72] and the methods of distribution [73].

Raw materials on world markets fluctuated over the considered period and had a direct impact on net prices. The price of energy is also influenced by the demand and its supply in a given country [74,75]. The import of non-renewable resources affects the energy security of the studied countries [76]. The most important threats to energy security are: the possibility of interrupting energy supplies from abroad, or damaging the production and transmission infrastructure, threats of cyber-terrorist attacks and the exhaustion of energy resources and consumption of energy infrastructure.

Differences in energy prices between the thirteen surveyed countries result from the way they are determined and the amount of taxes and charges set by the governments of these individual countries, and so they differ in environmental costs, taxes and compulsory fees.

During the analyzed period, gas was one of the basic sources of energy for households in the thirteen surveyed countries, except in Cyprus and Malta; their prices and taxes, as well as compulsory charges, were clearly differentiated and fluctuated periodically.

Due to the low number of electric cars in these countries, diesel and gasoline were a major part of household spending from 2010 to 2020 [35,77–79]. During the COVID-19 pandemic, most countries introduced sanitary regimes (lockdowns), which reduced the demand for gasoline and diesel fuel. Compulsory fees and taxes shaped the final fuel prices in individual countries.

The amount of electricity, natural gas, gasoline and diesel in the thirteen researched countries may have contributed to the reduction in demand. The authors' findings present that electricity in thirteen countries from 2010 to 2020 was mainly used for space and water heating, and its much smaller purchases led to energy poverty [50]. According to the European Energy Poverty Observatory, the main indicators of poverty are: low absolute energy consumption and the inability to maintain an adequate temperature in the home [80–82]. This phenomenon is largely due to lower household incomes in the thirteen countries compared to Western European countries. Energy poverty has a number of negative health consequences, due to low temperatures and the stress of being unable to pay energy bills [83,84]. Energy poverty directly affects the environment and labor productivity [85,86]. Solving this problem has many benefits, including reduced government spending on health, less pollution and CO_2 emissions, greater comfort and well-being and improved household budgets.

Moreover, the use of non-renewable resources for the production of electricity in the studied countries contributes to the increase in air pollution and CO_2 emissions, the reduction of which is required by the European Union [83,87]. Some of the analyzed countries will therefore face the problem of the dynamic development of RES in the current decade of the 21st century, especially as they do not have any major gas and crude oil sources [88]. Rising prices of non-renewable resources force countries to invest in new technologies and renewable energy sources. This process is likely to be accelerated by the outbreak of the war in February 2022 in Ukraine and the resignation from the purchase of non-renewable resources in Russia by some of the studied countries. Changes taking place in the markets of these countries may have a serious impact on the periodic increase in the price of energy and gas, crude oil and gasoline, as well as electricity, and contribute to the increase in energy poverty in the near future.

5. Conclusions

1. During the analyzed period, the energy consumption structure did not change significantly.
2. Electricity prices were steadily growing in the countries under assessment. Over the 10 years, the average purchase price of a kilowatt-hour, inclusive of taxes and levies, increased by EUR 0.05. The greatest increase in price was recorded in Latvia, whereas the price of 1 kilowatt-hour fell by EUR 0.07 in Hungary. The country also recorded the lowest net price of 1 kilowatt-hour in 2020. The greatest net price was recorded in the Czech Republic. In the EU countries, the share of taxes and charges was approximately 35.6% of the price. The taxes and fees were shaped by the governments of individual countries. The greatest percentage tax was imposed in Slovenia—35.5% of the final electricity price, whereas the lowest was in Malta—5.7%.
3. Gas was used in the majority of households in the countries under study. Only Cyprus and Malta did not use that source of energy. The greatest number of households that used gas was in Slovakia and the lowest number was in Bulgaria. During the period under review, there was a fluctuation in gas prices across the analyzed countries. The highest gas prices, including taxes and fees, were recorded in Slovakia—EUR 0.09.7 per kWh, whereas the lowest price was recorded in Romania—EUR 0.02.8 The greatest share of taxes and levies in the price of liquid fuels was recorded in Slovenia in 2020, whereas the lowest share was recorded in Romania.
4. The use of liquid fuels—petrol and diesel oil—in the countries under study, grew over the study period, and prices of fuel fluctuated over the period from 2010 to 2020. In 2010, the lowest price of petrol was recorded in Bulgaria and the greatest was in the Czech Republic. In 2020, diesel oil prices followed a similar pattern. The lowest price of diesel fuel was recorded in Bulgaria (EUR 0.92 per liter), whereas the highest was in Malta (EUR 1.24 per liter). The greatest increase in the price of diesel oil was recorded in Malta and the highest decrease was in the Czech Republic. When it comes to diesel, the greatest increase of price similarly was recorded in Malta and the highest decrease was in the Czech Republic.
5. In the countries under study, wages and salaries increased over the period from 2010 to 2020. However, annual household income was significantly lower than in the other states of the European Union. Inflation was a factor that influenced the level of consumption. Its rate varied in the countries under assessment. With regards to the ability to purchase certain raw materials in 2020, it should be noted that the greatest increase in the ability to buy electricity was recorded in Hungary (+153.87%), whereas the lowest was in Slovenia (+2.36%). In the case of natural gas, the largest increase in purchase power was in Lithuania (+253.6%). The most unfavorable situation was in the Czech Republic, where there was a decline in the purchase ability by 0.3%. With regards to petrol, the greatest increase in the purchase ability was in Romania, —146%, whereas the smallest was in Malta—+21%. Similarly, in the case of diesel oil, the greatest increase was recorded in Romania (+136%) and the smallest in Malta (+17%).

6. The COVID-19 pandemic, which broke out in March 2020, did not cause any significant changes in the prices of energy carriers in the analyzed period, apart from the declines in the prices of eurosuper 95 and diesel. It was not until 2021, which was not analyzed, that we noted significant changes in the price of raw materials and final energy prices. In addition, at the end of 2020, due to the COVID-19 pandemic, there were no significant changes in the tax policy with regard to energy resources. The highest taxation occurred in eurosuper 95 and diesel fuels—about 50% of the final price, whereas the lowest occurred in natural gas prices—around 20%.

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References

1. Małuszyńska, E.; Gruchman, B. *Kompendium Wiedzy o Unii Europejskiej*; PWN: Warsaw, Poland, 2018.
2. *European Economy, European Commission*; Directorate-General for Economic and Financial Affairs: Brussels, Belgium, 2004.
3. Compos, N.; Cricelli, F.; Moretti, L. Institutional Integration and economics growth in Europe. *J. Monet. Econ.* **2019**, *103*, 88–104. [CrossRef]
4. Belka, M. *How Poland's EU Membership Helped Transform its Economy*; 30 Occasional Paper 83; Group of Thirty: Washington, DC, USA, 2013.
5. Grabowska, I. The 2004 EU Enlargement as an Outcome of Public Policies: The Impact of Intra-EU Mobility on Central and Eastern European Sending Countries, *Soc. Policy Soc.* **2021**, *20*, 175–191. [CrossRef]
6. Owusu, P.A.; Asumadu-Sarkodie, S. A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Eng.* **2016**, *3*, 1167990. [CrossRef]
7. Liang, X. Emerging power quality challenges due to integration of renewable energy sources. *IEEE Trans. Ind. Appl.* **2017**, *53*, 855–866. [CrossRef]
8. Rokicki, T.; Perkowska, A. Changes in Energy Supplies in the Countries of the Visegrad Group. *Sustainability* **2020**, *12*, 7916. [CrossRef]
9. Rokicki, T.; Perkowska, A. Diversity and Changes in the Energy Balance in EU Countries. *Energies* **2021**, *14*, 1098. [CrossRef]
10. Rokicki, T.; Koszela, G.; Ochnio, L.; Wojtczuk, K.; Ratajczak, M.; Szczepaniuk, H.; Michalski, K.; Borawski, P.; Bełdycka-Borawska, A. Diversity and Changes in Energy Consumption by Transport in EU Countries. *Energies* **2021**, *14*, 5414. [CrossRef]
11. Van den Bergh, K.; Delarue, E.; D'haeseleer, W. Impact of renewables deployment on the CO_2 price and the CO_2 emissions in the European electricity sector. *Energy Policy* **2013**, *63*, 1021–1031. [CrossRef]
12. Cox, E. Assessing long-term energy security: The case of electricity in the United Kingdom. *Renew. Sustain. Energy Rev.* **2017**, *82*, 2287–2299. [CrossRef]
13. Lucia, J.J.; Schwartz, E.S. Electricity Prices and Power Derivatives: Evidence from the Nordic Power Exchange. *Rev. Deliv. Res.* **2002**, *5*, 5–50.
14. Huisman, R.; Mahieu, R. Regime jumps in electricity prices. *Energy Econ.* **2003**, *25*, 425–434. [CrossRef]
15. Raviv, E.; Bouwman, K.E.; Van Dijk, D. Forecasting day-ahead electricity prices: Utilizing hourly prices. *Energy Econ.* **2015**, *50*, 227–239. [CrossRef]
16. Maekawa, J.; Hai, B.H.; Shinkuma, S.; Shimada, K. The Effect of Renewable Energy Generation on the Electric Power Spot Price of the Japan Electric Power Exchange. *Energies* **2018**, *11*, 2215. [CrossRef]
17. Covern, M.; Heald, S.; Pirie, J. *Oil Dependency in the EU*; Cambridge Econometrics: Cambridge, UK, 2020; Available online: https://www.transportenvironment.org/wpcontent/uploads/2021/07/2020_CE_Oil_Dependency_in_EU_report.pdf (accessed on 10 April 2022).
18. Miller, R.G.; Sorrell, S.R. The future oil supply. *Philos. Trans. A Math. Phys. Eng Sci.* **2014**, *372*, 20130179. [CrossRef] [PubMed]
19. Arezki, R.; Jakab, Z.; Laxton, D.; Matsumoto, A.; Nurbekyan, A.; Wang, H.; Yao, J. Oil Prices and the Global Economy. *IMF Work. Pap.* **2017**, *17*, 1. [CrossRef]

20. Kanai, M. Decoupling the Oil and Gad Prices. In *Natural Pricing in the Post-Financial Crisis Market*; Federal Reserve Bank of Dallas: Brussels, Belgium, 2011; Available online: https://www.ifri.org/sites/default/files/atoms/files/noteenergiemiharukanai.pdf (accessed on 10 April 2022).
21. Wages Determinants in the European Union Updated Results from Structure of Earnings Survey (SES 2018) DATA 2021 Edition. Available online: https://ec.europa.eu/eurostat/documents/7870049/12810163/KS-FT-21-004-EN-N.pdf/178c1845-cf78-60fe-495e-59c4c1d72f32?t=1621928655427 (accessed on 10 April 2022).
22. Afonso, O.; Albuquerque, A.L.; Almeida, A. Wage inequality determinants in European Union countries. *Appl. Econ. Lett.* **2013**, *20*, 1170–1173. [CrossRef]
23. Barnes Atkinson, A.; Malier, E. *Income and Living Condicions in Europe*; Eurostat: Luxembourg, 2010; Available online: https://ec.europa.eu/eurostat/documents/3217494/5722557/KS-31-10-555-EN.PDF (accessed on 10 April 2022).
24. Galgóczi, B. Why Central and Eastern Europe Needs a Pay Rise. Available online: https://www.etui.org/sites/default/files/WP%202017-01-pay%20rise-HD-web%20version%20finale.pdf (accessed on 10 April 2022).
25. Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity. *Off. J. Eur. Communities* **1996**, *L27*, 20–29.
26. European Union. Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC. *Off. J. Eur. Union.* **2003**, *L176*, 37–55.
27. European Union. Directive of 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC. *Off. J. Eur. Union.* **2009**, *211*, 55–93.
28. European Commission. *Energy 2020. A Strategy for Competitive, Sustainable and Secure Energy*; The Publications Office of the European Union: Brussels, Belgium, 2010.
29. European Commission. *Energy Roadmap 2050*; Publications Office of the European Union: Luxembourg, Luxembourg, 2012.
30. European Commission. *Energy Union Package*; The Publications Office of the European Union: Brussels, Belgium, 2011.
31. European Commission. *A Framework Strategy for a Resilient Energy Union with a Forward Looking Climate Change Policy*; The Publications Office of the European Union: Brussels, Belgium, 2015.
32. Council Directive 92/81/EEC of 19 October 1992 on the harmonization of the structures of excise duties on mineral oils. *OJL* **1992**, *316*, 12–15.
33. Kopits, G. *Tax harmonization in the European Community*; Policy Issues and Analysis; International Monetary Fund: DC, USA, 1992; ISBN 9781557752253.
34. Hoeller, P.; Louppe, M.; Vergriete, P. *Fiscal Relations within the European Union*; OECD Economics Department Working Papers, No. 163; OECD Publishing: Paris, France, 1996. [CrossRef]
35. Rokicki, T.; Borawski, P.; Bełdycka-Borawska, A.; Żak, A.; Koszela, G. Development of Electromoblity in Eurorpean Union under COVID-19 Condictions. *Energies* **2022**, *15*, 9. [CrossRef]
36. Drożdż, W.; Starzyński, P. Economic conditions for the development of electromobility in Poland compared to selected countries. *Eur. J. Serv. Manag.* **2018**, *28*, 133–140. [CrossRef]
37. Ramsey, M. Ford Reveals How Much Electric-Car Batteries Cost. *Wall Str. J.* **2012**, 1–27. Available online: http://blogs.wsj.com/drivers-seat/2012/04/17/ford-reveals-how-much-electric-car-batteries-cost (accessed on 10 July 2021).
38. Dano, F.; Rehák, R. Electromobility in the European Union and in the Slovakia and its Development Oportunies. *Int. J. Multiciscplinary Bus. Sci.* **2018**, *4*, 74–83. Available online: https://hrcak.srce.hr/file/302226 (accessed on 10 July 2021).
39. Połom, M.; Wiśniewski, P. Implementing Electromobility in Public Transport in Poland in 1990–2020. A Review of Experiences and Evaluation of the Current Development Directions. *Sustainability* **2021**, *13*, 4009. [CrossRef]
40. Castelli, M.; Beretta, J. Development of electromobility in France: Causes, facts and figures. *Electr. World Veh. J.* **2016**, *8*, 772–782. [CrossRef]
41. Andrae, A.S.G.; Edler, T. On Global Electricity Usage of Communication Technology: Trends to 2030. *Challenges* **2015**, *6*, 117–157. [CrossRef]
42. Feckova Skrabulakova, E.; Ivanova, M.; Rosova, A.; Gresova, E.; Sofranko, M.; Ferencz, V. On Electromobility Development and the Calculation of the Infrastructural Country Electromobility Coefficient. *Processes* **2021**, *9*, 222. [CrossRef]
43. Sierzchula, W.; Bakker, S.; Maat, K.; Van Wee, B. The influence of financial incentives and other socio-economic factors on electric vehicle adoption. *Energy Policy.* **2014**, *68*, 183–194. [CrossRef]
44. Łuszczyk, M.; Sulich, A.; Siuta-Tokarska, B.; Zema, T.; Thier, A. The Development of Electromobility in the European Union: Evidence from Poland and Cross-Country Comparisons. *Energies* **2021**, *14*, 8247. [CrossRef]
45. Pelau, C.; Acatrinei, C. The Paradox of Energy Consumption Decrease in the Transition Period towards a Digital Society. *Energies* **2019**, *12*, 1428. [CrossRef]
46. European Comission. Energy Prices and Costs in Europe. Available online: https://ec.europa.eu/energy/sites/default/files/documents/swd2020_951_-_1_en_autre_document_travail_service_part3_v1.pdf (accessed on 22 February 2022).
47. Tsemekidi Trzeiranak, S.; Bertoldi, P.; Paci, D.; Castellazzi, L.; Ribeiro Serrenho, T.; Economidou, M.; Zangheri, P. *Energy Consumption and Energy Efficiency Trends in EU-28, 2000–2018*; JRC JRC120681; Publications Office of the European Union: Luxembourg, Luxembourg, 2020. [CrossRef]

48. European Commissio. *Clean Energy for All Europeans. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, the Committee of the Regions and the European Investment Bank*; Publications Office of the European Union: Brussels, Belgium, 2016.
49. Hortaçsu, A.; Madanizadeh, S.A.; Puller, S.L. Power to choose? An analysis of consumer inertia in the residential electricity market. *Am. Econ. J. Econ. Policy* **2017**, *9*, 192–226. [CrossRef]
50. Rokicki, T.; Borawski, P.; Gradziuk, B.; Gradziuk, P.; Mrówczyńska-Kamińska, A.; Kozak, J.; Guzal-Dec, D.J.; Wojtczuk, K. Differentiation and Changes of Household Electricity Prices in EU Countries. *Energies* **2021**, *14*, 6894. [CrossRef]
51. Eurostat. Electricity Prices for Household Consumers—Bi-Annual Data (from 2007 Onwards). Available online: https://ec.europa.eu/eurostat/databrowser/view/NRG_PC_204/default/table?lang=en (accessed on 22 February 2022).
52. Verbič, M.; Filipovič, S.; Radovanovič, M. Electricity prices and energy intensity in Europe. *Util. Policy* **2017**, *47*, 58–68. [CrossRef]
53. Price, C.W.W.; Zhu, M. Non-discrimination clauses: Their effect on British retail energy prices. *Energy J.* **2016**, *37*, 111–132.
54. Lebelhuber, C.; Steinmuller, H. How and the which extent can the gas sector contribute to a climate-neutral European energy system? A qualitative approach. *Energy Sustain. Society* **2019**, *9*, 23. [CrossRef]
55. Cătuţi, M.; Egenhofer, C.; Elkerbout, M. The Future of Gas in Europe: Review of Recent Studies on the Future of Gas. Research Report 03/2019. 2019. Available online: https://www.ceps.eu/wp-content/uploads/2019/08/RR2019-03_Future-of-gas-in-Europe.pdf (accessed on 22 February 2022).
56. Kostakis, I. Socio-demographic determinants of household electricity consumption: Evidence from Greece using quantile regression analysis. *Curr. Res. Environ. Sustain.* **2020**, *1*, 23–30. [CrossRef]
57. Bellocchi, S.; Manno, M.; Noussan, M.; Vellini, M. Impact of Grid-Scale Electricity Storage and Electric Vehicles on Renewable Energy Penetration: A Case Study for Italy. *Energies* **2019**, *12*, 1303. [CrossRef]
58. Wróblewski, P.; Drożdż, W.; Lewicki, W.; Dowejko, J. Total Cost of Ownership and Its Potential Consequences for the Development of the Hydrogen Fuel Cell Powered Vehicle Market in Poland. *Energies* **2021**, *14*, 2131. [CrossRef]
59. Available online: https://www.iea.org/articles/global-ev-data-explorer (accessed on 22 February 2022).
60. Available online: https://ec.europa.eu/energy/observatory/reports/latest_prices_with_taxes.xlsx (accessed on 18 February 2022).
61. Brandolini, A.; Rosolia, A. *The Distribution of Well-Being Among Europeans. Europe's Income, Wealth, Consumption, and Inequality*; Fischer, G., Strauss, R., Eds.; Oxford University Press: Oxford, UK, 2021.
62. Almeida, V.; Barrios, S.; Christl, M.; De Poli, S.; Tumino, A.; Van der Wielen, W. *Households ´ Income and the Cushioning Effect of Fiscal Policy Measures during the Great Lockdown*; JRC Working Papers on Taxation and Structural Reforms 06/2020; European Commission, Joint Research Centre: Seville, Spain, 2020.
63. Fischer, G.; Strauss, R. *Europe's Income, Wealth, Consumption, and Inequality*; Oxford University Press: Oxford, UK, 2021.
64. Eurostat. Annual Net Earnings. Available online: https://ec.europa.eu/eurostat/databrowser/view/earn_nt_net/default/table?lang=en (accessed on 22 February 2022).
65. Eurostat. Database. Available online: https://ec.europa.eu/eurostat/web/hicp/data/database (accessed on 22 February 2022).
66. Ketterer, J.C. The impact of wind power generation on the electricity price in Germany. *Energy Econ.* **2014**, *44*, 270–280. [CrossRef]
67. Martinez-Anido, C.B.; Brinkman, G.; Hodge, B.M. The impact of wind power on electricity prices. *Renew. Energy.* **2016**, *94*, 474–487. [CrossRef]
68. Ballester, C.; Furió, D. Effects of renewables on the stylized facts of electricity prices. *Renew. Sustain. Energy Rev.* **2015**, *52*, 1596–1609. [CrossRef]
69. Cruz, A.; Muñoz, A.; Zamora, J.L.; Espínola, R. The effect of wind generation and weekday on Spanish electricity spot price forecasting. *Electr. Power Syst. Res.* **2011**, *81*, 1924–1935. [CrossRef]
70. Paska, J.; Sałek, M.; Surma, T. Current status and perspectives of renewable energy sources in Poland. *Renew. Sustain. Energy Rev.* **2013**, *13*, 142–154. [CrossRef]
71. Streimikiene, D.; Kyriakopoulos, G.L.; Lekavicius, V.; Siksnelyte-Butkiene, I. Energy Poverty and Low Carbon Just Energy Transition: Comparative Study in Lithuania and Greece. *Soc. Indic. Res.* **2021**, *158*, 319–371. [CrossRef] [PubMed]
72. Sun, W.; Zhang, H.; Tseng, M.-L.; Zhang, W.; Li, X. Hierarchical energy optimization management of active distribution network with multi-microgrid system. *J. Ind. Prod. Eng.* **2022**, *39*, 210–229. [CrossRef]
73. Chen, W.-C.; Chen, W.-K.; Chen, C.-W.; Lo, C.-C. An empirical study of willingness to renewable energy installation using importance-performance analysis: The case of Taiwan. *J. Ind. Prod. Eng.* **2019**, *36*, 451–460. [CrossRef]
74. Ouyang, Z.-Y.; Qin, Z.; Cao, H.; Xie, T.-Y.; Dai, X.-Y.; Wang, Q.-W. A Spillover Network Analysis of the Global Crude Oil Market: Evidence from the post-financial crisis era. *Pet. Science* **2021**, *18*, 1256–1269. [CrossRef]
75. Kilian, L.; Zhou, X. *Oil Prices, Gasoline Prices and Inflation Expectations: A New Model and New Facts*; Working Paper 2025; Federal Reserve Bank of Dallas: Dallas, TX, USA, 2020; Available online: https://www.dallasfed.org/-/media/documents/research/papers/2020/wp2025.pdf (accessed on 10 April 2022).
76. Khattak, M.A.; Ayoub, M.A.H.; Manaf, A.F.A.; Mahrul, M.F.; Juhari, M.R.M.; Mustaffa, M.I.; Kazi, S. Global Energy Security and European Union: A Review. *J. Adv. Res. Appl. Sci. Eng. Technol.* **2018**, *11*, 64–81. Available online: https://akademiabaru.com/submit/index.php/araset/article/view/1961/1533 (accessed on 10 April 2022).
77. Kucukvar, M.; Onat, N.C.; Kutty, A.A.; Abdella, G.M.; Enis Bulak, M.; Ansari, F.; Kumbaroglu, G. Environmental efficiency of electric vehicles in Europe under various electricity production mix scenarios. *J. Clean. Prod.* **2022**, *335*, 130291. [CrossRef]

78. Tsakalidis, A.; Thiel, C. *Electric Vehicles in Europe from 2010 to 2017: Is Full-Scale Commercialisation Beginning? An overview of the Evolution of Electric Vehicles in Europe*; JRC Science for Policy Report EUR 29401 EN; Publications Office of the European Union: Luxembourg, 2018. [CrossRef]
79. Gomez Vilchez, J.J.; Julea, A.; Peduzzi, E.; Pisoni, E.; Krause, J.; Siskos, P.; Thiel, C. Modelling the impacts of EU countries' electric car deployment plans on atmospheric emissions and concentrations. *Eur. Transp. Res. Rev.* **2019**, *11*, 1–17. [CrossRef]
80. European Union Comission Recommendation no. 2020/1563 of 14 October 2020 on Energy Poverty. Available online: https://eur-lex.europa.eu/legal-content/PL/TXT/HTML/?uri=CELEX:32020H1563&from=EN (accessed on 10 April 2022).
81. Streimikiene, D.; Lekavičius, V.; Baležentis, T.; Kyriakopoulos, G.L.; Abrhám, J. Climate Change Mitigation Policies Targeting Households and Addressing Energy Poverty in European Union. *Energies* **2020**, *13*, 3389. [CrossRef]
82. Stankuniene, G.; Streimikiene, D.; Kyriakopoulos, G.L. Systematic Literature Review on Behavioral Barriers of Climate Change Mitigation in Households. *Sustainability* **2020**, *12*, 7369. [CrossRef]
83. Turnock, S.T.; Butt, E.W.; Richardson, T.B.; Mann, G.W.; Reddington, C.L.; Forster, P.M.; Haywood, J.; Crippa, M.; Janssens-Maenhout, G.; Johnson, C.E. The impact of European legislative and technology measures to reduce air pollutants on air quality, human health and climate. *Environ. Res. Lett.* **2016**, *11*, 024010. [CrossRef]
84. Juginović, A.; Vuković, M.; Aranza, I.; Biloš, W. Health impacts of air pollution exposure from 1990 to 2019 in 43 European countries. *Sci. Rep.* **2021**, *11*, 22516. [CrossRef]
85. Holian, M.J. The impact of building energy codes on household electricity expenditures. *Econ. Lett.* **2020**, *186*, 108841. [CrossRef]
86. Kan, X.; Reichenberg, L.; Hedenus, F. The impacts of the electricity demand pattern on electricity system cost and the electricity supply mix: A comprehensive modeling analysis for Europe. *Energies* **2021**, *235*, 121329. [CrossRef]
87. Sicard, P.; Agathokleous, E.; De Marco, A.; Paoletti, E.; Calatayud, V. Urban population exposure to air pollution in Europe over the last decades. *Environ. Sci. Eur.* **2021**, *33*, 28. [CrossRef]
88. Ahmadov, A.K.; Van der Borg, C. Do natural resources impede renewable energy production in the EU? A mixed-methods analysis. *Energy Policy* **2019**, *126*, 361–369. [CrossRef]

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Analysis and Evaluation of the Photovoltaic Market in Poland and the Baltic States

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Abstract: The household, industrial, and service sectors in Poland and the Baltic States have been facing ever-higher bills for their electricity consumption at a time when a number of them have been hit hard financially by the pandemic. Rising inflation, the border crisis—with its set of restrictions, or the spread of the fourth wave of the COVID-19 coronavirus pandemic, is causing strong concerns in the social and economic sphere, with significant increases in electricity prices. Many countries are implementing measures to reduce the adverse effects of rising electricity prices in response to this complex situation. The main orientation is towards obtaining energy from renewable sources, such as the sun. The current situation in the energy market determines the price per 1 KW. Among the countries under study, the price of electricity has increased the most in Poland. On the other hand, the development of the photovoltaic segment in Poland is undergoing a strong, upward trend. The above inspired the authors to explore the energy market situation in Poland and the Baltic States in the current economic conditions, along with an analysis of its development potential in light of the coronavirus pandemic. The main research problem of this study is an attempt to answer the question of what should be changed in the development of the renewable energy market in Poland, with particular emphasis on photovoltaics, to accelerate the process of reducing CO_2 emissions, leading to a reduction in dramatically rising electricity prices. Which solutions implemented in the Baltic countries can inspire strengthening Poland's energy market development?

Keywords: energy market; renewable energy; electricity prices; photovoltaics; renewable energy

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1. Introduction

The household, industrial, and service sectors in Poland and the Baltic States have been facing ever-higher bills for their electricity consumption at a time when a number of them have been hit hard financially by the pandemic. Rising inflation, the border crisis—with its set of restrictions, or the spread of the fourth wave of the COVID-19 coronavirus pandemic, is causing solid concerns in the social and economic sphere, with significant increases in electricity prices. In response to this complex situation, several countries are implementing measures to reduce the negative effects of electricity price increases. In addition to actions in the regulatory sphere, affecting the price of electricity or the system of subsidies to the costs of its purchase, the system of actions related to the promotion of alternative formulas for obtaining electricity, oriented towards the modification of energy markets based on traditional sources (fossil fuels) to an energy economy based on renewable energy sources (wind energy, solar energy, geothermal energy, wave energy, current and tidal energy, energy from the fall of rivers, biomass energy) [1] is fundamental. This seems to be an absolute necessity [2], and the support in the field of eco-installations (especially in the financial sphere) is an important impulse for taking up the challenges in this area.

The authors concluded that renewable energy sources should be the basis for developing the energy market in the world. Although this is an obvious aspect related to the dimension of the modern energy economy, many differences can be observed in the progress of implementation of RES solutions and the types of undertaken solutions, reflected in the price of electricity per 1 kWh. Significant differences in this respect can be observed in the example of countries of the Baltic Sea basin, where Poland leads in the production of electricity from non-renewable sources (82%) [3]. The context outlined above justifies the need to investigate the current situation of the energy market in Poland and in the Baltic countries as its stability directly translates into efficient functioning of entities in this area in the social [4] and economic [5] dimensions.

Having the above in mind, the general purpose of the paper is to examine the differences in the progress of the Baltic Sea countries in implementing solutions related to obtaining energy from renewable sources. The rationale for choosing the Baltic Sea countries is their direct vicinity and the similar general social and economic conditions of Poland and the Baltic countries, providing the basis for substantive comparisons.

The main objective of this study was to investigate the current situation of the energy market in Poland and the Baltic States, with a particular focus on photovoltaics as a direction for the development of alternative forms of electricity generation. This choice is supported by the fact that Poland, as the least advanced country in the field of renewable energy, has been recently leading the way in terms of photovoltaic development. The objectives of this paper are to diagnose the state of the electricity market in the current economic conditions, to present the essence of the photovoltaic process and to analyze the potential development of the photovoltaic market in Poland and the Baltic countries, as well as to assess the impact of the coronavirus pandemic COVID-19 on the development of the photovoltaic market in Poland and the Baltic countries. The main research problem of this study, however, is an attempt to answer the question of what can be changed in the development of the renewable energy market in Poland, with particular emphasis on photovoltaics, to accelerate the process of reducing CO_2 emissions, leading to a reduction in dramatically rising electricity prices. Which of the solutions implemented in the Baltic countries can be an inspiration to strengthen the development of the energy market in Poland, based on renewable energy sources?

Similar studies have been conducted in different countries. It is worth pointing out that the literature on the subject provides numerous examples of studies of the energy market in the countries of the Baltic Sea basin, most often realized for the Baltic countries—Lithuania, Latvia, and Estonia [1], thus including Poland in analyses of this type will broaden their spectrum, limiting a kind of research gap. The above is justified by the current need for information on the energy market in the region, which is another reason for establishing a research area for this study. The selected countries are also characterized by a differentiated approach to the implementation of solutions allowing for obtaining energy from renewable sources, which is confirmed, among others, by the content of the Sustainable Development Report 2019: Transformations to Achieve the Sustainable Development Goals, according to which Estonia is in the lead, ranking 10th in the ranking of 193 UN member states in terms of changes in indicators for the Sustainable Development Goals by 2030 (including the green energy index), followed by Latvia in 24th place, Poland in 29th place and Lithuania in 32nd place [6]. In addition, the selection of countries was based on the availability of analytical data in Eurostat and industry reports published, among others, on the Internet to ensure comparability of data and appropriate quality of research results.

The paper adopts the following structure: Section 1 contains the introduction, Section 2 contains the literature review on the development of the photovoltaic energy market in the world. Section 3 presents the results of the research on the analysis of the photovoltaic market in Poland and the Baltic States along with the assessment of its development trends, taking into account the impact of the coronavirus pandemic and the recommendations formulated based on the research results Section 4 contains the discussion and conclusions.

2. Global Photovoltaic Market Development—Literature Review

The efficiency of the energy market determines economic development. The professional literature provides numerous analyses in the field of the influence of energy factors on the growth of individual economies worldwide [7–10]. The above gains particular significance in the era of the coronavirus pandemic where, on the one hand, the reduction in the extraction of fossil fuels has contributed to a change in consumer behavior and an increase in demand for energy obtained from renewable sources [11], and, on the other hand, the support for the development of the renewable energy market takes place at the expense of supporting the fossil fuel extraction sectors in the countries dependent on this industry [12]. Actions promoting the acquisition of green energy—essentially limiting its cost—seem to be highly justified in the reality of the crisis caused by the pandemic. The above should be mainly considered in countries whose main energy production capacities are concentrated around non-renewable sources. The recently observed increases in energy prices in countries where energy is obtained traditionally (e.g., Poland) [13] deepen the general rise in prices, which may be the basis for social unrest [14].

The virtues of green energy are recognized by many countries, contributing to changes in energy acquisition policies [15,16]. Individual economies are opening up to Sustainable Development [6] and increasing energy efficiency. Awareness about the negative impact of the traditional energy sector on the environment is increasing, and its effects on climate change [17,18] are increasingly raised. Therefore, caring for the environment and the search for alternatives to classical, nature-harming solutions in the sphere of energy acquisition and distribution have become more important than ever. "Green energy" convinces the world and is currently a desired trend in developing the global energy market. Maintaining high, in global terms, demand for electricity, with rising prices for 1 KW of energy produced traditionally—correlated with the increasing level of environmental fees—justifies the above from an economic point of view. The above applies particularly strongly to Poland, which depends on traditional forms of energy generation [19,20] and needs urgent changes in the energy sector, affecting technological, environmental, and economic aspects [21]. The opening to distributed energy from RES sources is marked in the Polish Energy Policy and its subsequent revisions [22,23].

The global RES market is growing, [12] especially the solar and wind energy sectors, and the coronavirus pandemic has not slowed down this development [19], which can be confirmed in the literature [24,25]. Strong development of the indicated sectors of the RES market empowered the authors in the choice of exploring, within the framework of this article, the thread of one of them—a technique-oriented to the conversion of energy obtained from solar radiation into electricity, based on the photovoltaic effect. What does it consist of?

The accumulation of solar energy (photon strands) into charge in a semiconductor takes place in a photovoltaic unit (cell), which builds the energy conversion module—the photovoltaic panel. The essence of the process arises from the construction of photovoltaic cells, which in most cases consist of a semiconductor in the form of silicon crystals (monocrystalline or polycrystalline), the irradiation of electrons building which, releases a higher energy level (electron-hole). The burst and movement of the electrons trigger a potential difference and the phenomenon of DC accumulation. At the same time, in the inverter, its conversion from alternating to direct current [26] is carried out. The photovoltaic process outlined above is based on the quality of the silicon crystals. Its type and structure determine the quality of the equipment for converting solar energy into electricity. The efficiency of the photovoltaic effect is therefore created on the technical side by the number of electrons and the number of bonds, which is combined with the quality of the solar energy, determined by the intensity and the length of the solar radiation resulting from the geographical location of the photovoltaic installation [27] (longitude and latitude, correlated with the time of the calendar year) and the correct choice and achievement of the optimal direction and degree of inclination of the photovoltaic installation at the place of solar energy intake (azimuth). Also important is the surface type under the PV modules [28]. The quality of the semiconductor used—its crystal structure, the type of cell bonding used, and the type of anti-reflective coatings applied—is therefore important in selecting a solution [24]. The quality of solar radiation, correlated with the conditions of its reception and conversion [29,30], determines the energy efficiency of a specific solution.

Renewable energy is on the rise in response to global demand. Solar energy is growing mainly in the sunnier parts of the world, but it is also becoming increasingly important in less sunny regions. For example, China achieved spectacular results in the photovoltaics field with a connection capacity in 2020 of 48.2 GW, and the USA has achieved 19.2 GW [31]. In addition, India and Saudi Arabia have achieved outstanding results in the photovoltaic sector [32].

Solar energy in the European Union has grown strongly over the past few years [33–35]. Hence, the photovoltaic sector is an important pillar of green energy in the European energy market [36]. The undisputed leader in the photovoltaic sector in the European market is Germany with a total connected capacity of more than 50 GW, followed by Italy (21 GW), the United Kingdom (13.3), while Poland in this ranking is in the second ten [37], ahead of the Baltic States.

The above literature review provides a background for further research—oriented towards analyzing the photovoltaic market in Poland and the Baltic States, in line with the objective presented in the introduction.

3. Materials and Methods

The research at the outset was conceptual in nature. However, the considerations undertaken in this article are analytical and empirical. The research was based on the analysis of industry reports on the energy market in Poland and the Baltic countries (Lithuania, Latvia, and Estonia), statistical studies communicated at the level of the countries adopted for the analysis, as well as relating to the European Union market in general, and on the results of own research on the development of the photovoltaic micro-installation segment in the energy market in Poland, in the topic of determinants of investment decisions, in connection with the purchase of photovoltaic solutions. Systematization and decomposition techniques and comparative and situational analysis methods were used. In addition, methods typical for planning and forecasting were used. Figure 1 presents the research algorithm.

The study was based on an extensive literature list. In addition, a content analysis of world literature on the photovoltaic energy market and industry reports on the latest trends in the development of the energy sector was carried out to show trends and new solutions applicable in the studied countries. Although the topic addressed in this paper is quite important and relevant, there are different models in the scientific and journalistic literature for the introduction of PV and its participation in the overall energy market. Furthermore, there are a limited number of national studies devoted to analyzing the prospects of the domestic photovoltaic industry from the perspective of the global energy transition. Therefore, the basis of the research is primarily foreign scientific articles, studies, and international reports, forecasts, predictive estimates, and statistical data.

The authors have tried to cover the main trends and issues related to the discussed topic and have consistently moved from the global experience to the Polish and Baltic experiences to answer the questions posed in the research. To gain insight into the Polish intentions related to energy transition trends, a critical analysis of the current situation has been carried out, and conclusions from final consumer behavior surveys and interviews conducted among representatives of companies active in the energy transition have been presented.

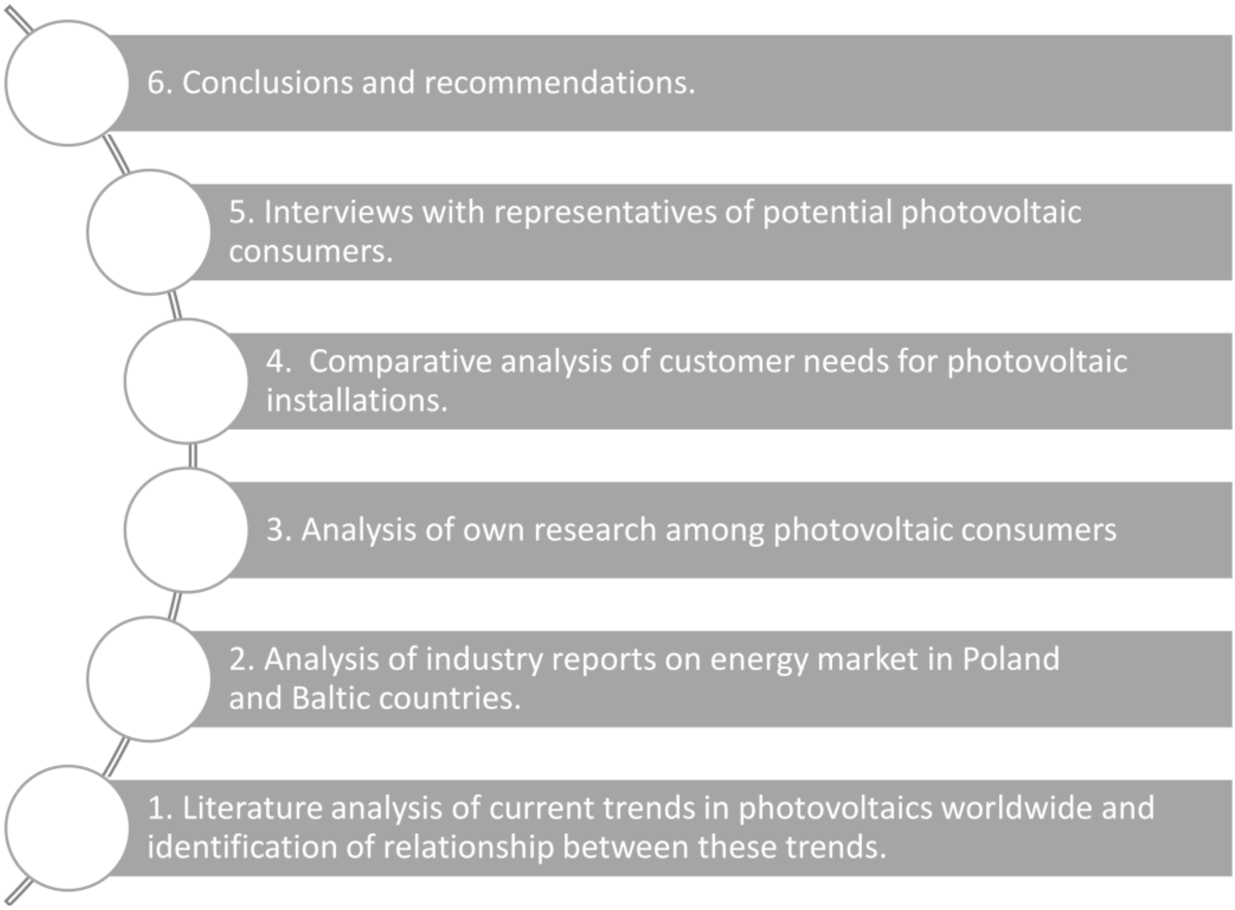

Figure 1. Research algorithm [38].

The authors intend to deepen their knowledge and collect results on the production of "green" technologies to develop a model that best fits the realities of the Polish and Baltic economies. In order to obtain a common vision of current plans and intentions and collect quantitative data from pro consumers, the authors have now extended the survey and conducted interviews to obtain reliable forecast estimates.

4. Results

4.1. Diagnosis of the Energy Market Situation in Poland and the Baltic States

The degree of advancement of efforts to reduce conventional electricity generation, correlated with the level of CO_2 emissions [39] and regulatory processes regarding its permissible levels (with rising prices of carbon allowances), determines the price system per 1 KW. The above is also influenced by the situation of economies operating in pandemic realities and the increase in prices of energy raw materials; hence, the changes in electricity prices in Poland and the Baltic States (Lithuania, Latvia, and Estonia) are differentiated in terms of their degree and direction. The most significant price increase in the analyzed set of countries concerns the Polish energy market, with the increase in the period 2019–2020 also covering the Lithuanian energy market. Latvia saw an increase in prices per 1 KW only in the current year, while electricity prices in Estonia are gradually decreasing, although already at a minimum level in the current period. (Table 1).

The level of average prices per 100 kWh of electricity in the period 2019–2021 in Poland and the Baltic States, expressed in European currency, assumed the following values—Table 2.

The varying pattern of electricity prices across European economies shapes the average price per 100 kWh in the European Union, which remains relatively stable—Figure 2.

Table 1. Average changes in electricity prices between 2019 and 2021 in Poland and the Baltic States, relative to national currencies [40].

The Average Change in Electricity Prices in Poland and the Baltic States in the Period 2019–2021 Relative to National Currencies			
	2019	**2020**	**First Half of 2021**
Poland	+9.7	+14.1	+8
Lithuania	+5	+5.3	−6
Latvia	−8	−12.7	+7
Estonia	−13	−8.5	−1

Table 2. Changes in average electricity prices per 100 KWh in 2019–2021 in Poland and the Baltic States [40].

Average Electricity Price during the Period 2019–2021/100 KWh, Expressed in Euro			
	2019	**2020**	**First Half of 2021**
Poland	13.76	15.1	15.48
Lithuania	12.54	13.2	13.48
Latvia	16.4	14.3	14.03
Estonia	14.11	12.9	13.24

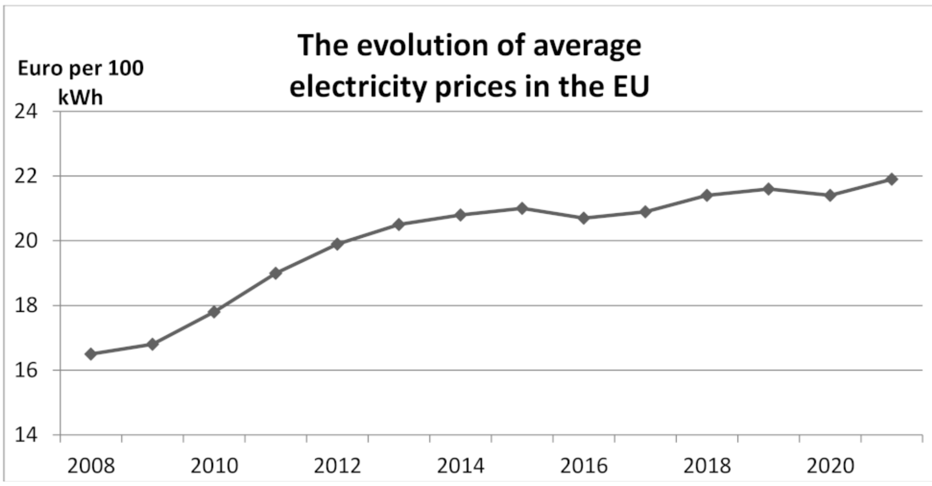

Figure 2. The evolution of average electricity prices per 100 KWh between 2019 and 2021 in the European Union [41].

Against the background of the analyzed group of countries, Poland adopts the highest electricity price increases. This increase in electricity after 1 January 2020 was released by the expiry of the Act on electricity prices binding until the end of 2019, hence after 1 January 2020, there was a strong increase of almost 20%, motivated by the current price of CO_2 emission allowances, as well as an increase in generation costs and related prices for hard coal and lignite. Changes in prices are also shaped by the change in the value of the distribution fee, determined by the economic situation [42]. It is worth noting that the structure of distribution fees is shaped by as many as nine cost items, which include: the charge for commissioned power, subscription fee, cost of active energy, cost of distribution fixed, cost of the distribution variable, quality charge, transitional charge, renewable energy sources charge (RES), cogeneration levy.

The system of retail electricity prices of Poland in the period 2017–2021 increased significantly, and the average selling price of 1 kWh adopted the following values: PLN 0.55 in 2017–2019, PLN 0.62 in 2020, and PLN 0.63 in 2021 (with the cost arrangement:

PLN 0.38 per 1 kWh plus PLN 0.25 per 1 kWh for distribution charges). According to the announcement of the Energy Regulatory Office, further increases of both electricity purchase tariffs (as a rule G11 or G12) and the components of distribution fees are to be expected, wherein 2022, the fee for ordered power is to increase by approximately 21%, and assumed price levels between PLN 2.37 and PLN 13.25 PLN [43] in the monthly settlement.

Electricity exchange prices in Poland in September 2021 reached a record level of 401 PLN per MWh (historically 120 EUR), achieving a 68% increase compared to August. However, compared to the Baltic States, it is a relatively good result. For example, the level of exchange prices in the corresponding period in Lithuania and Latvia amounted to 143 Euro per 1 MWh, while in Estonia it was 142 Euro per 1 MWh [44]—Figure 3.

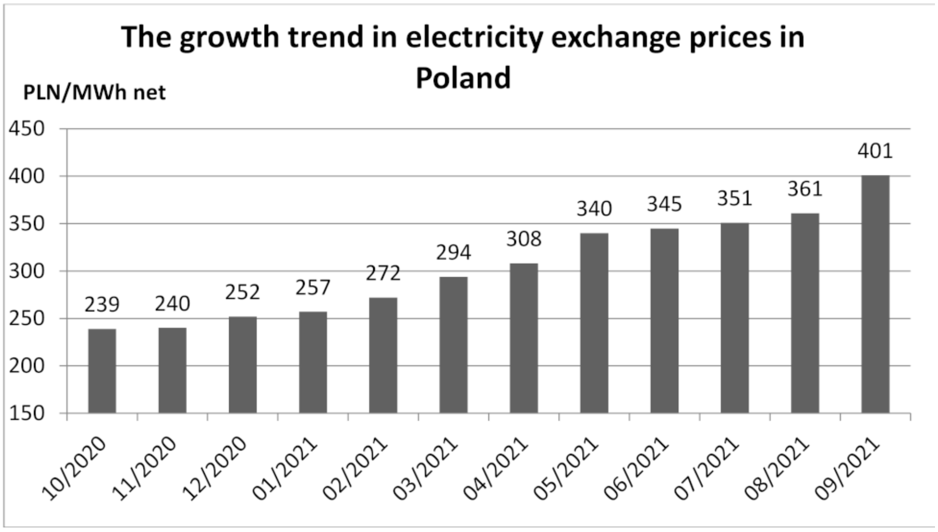

Figure 3. The growth trend in electricity exchange prices in Poland is October 2020–September 2021 [45].

Wholesale electricity prices on the European Union market have also been increasing. An analysis of the trend in wholesale prices in the European energy market is presented in Figure 4.

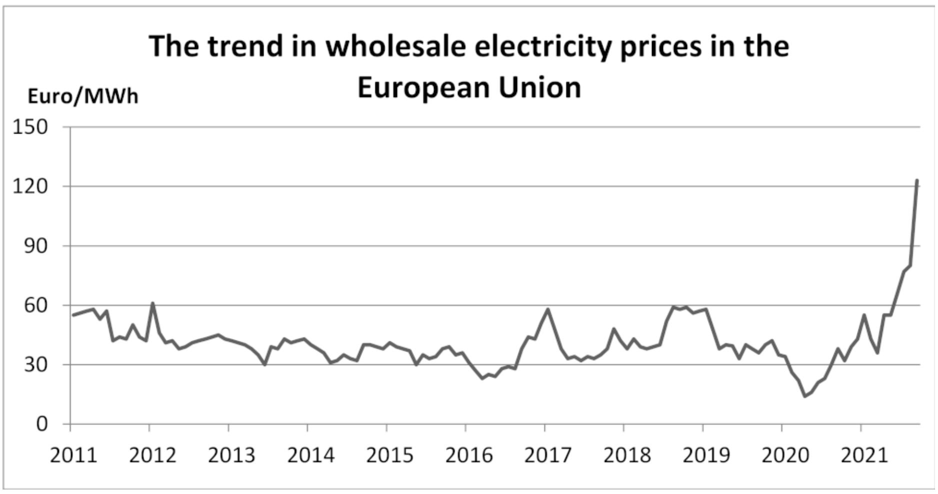

Figure 4. The trend in electricity exchange prices in the European Union from January 2011 to September 2021. [46].

The observed price increase trend means a real increase in electricity prices for the household sector in Poland and the Baltic States, which in Q1 this year amounted to: in Poland: 26.34, in Lithuania: 19.42, in Latvia: 19.46, in Estonia: 16.64 PPS per 100 KW.

An analysis of the trend in electricity prices in Poland does not give cause for optimism regarding the forecast of future purchase costs for electricity, which is produced mainly based on the classic generation model. There are over 50% share in the structure of electricity production in Poland is correlated with the cost of purchasing more expensive energy resources and CO_2 emission allowances, which is currently over EUR 2.1 billion [43]. The need to seek alternatives to conventional sources of electricity generation is undeniable. A solid opening to green energy and the reconstruction of generation infrastructure, associated with investments of significant value, is essential. In this regard, photovoltaic solutions are attractive—recommended under the technical criterion in the subject of a wide range of applications and for legal, economic, and safety reasons [47,48].

4.2. Analysis of the Photovoltaic Market in Poland and the Baltic States

The photovoltaic market is developing rapidly in Poland and the Baltic States. The above is determined by current eco-trends, which are referred to in the energy policies of European and world economies, which aim to increase energy independence while reducing harmful environmental impacts (CO_2 emissions, groundwater declines, and permanent destruction of ecosystems). Undoubtedly, the generation of electricity from solar radiation is becoming an increasingly popular response to the challenge outlined above, so the promotion and support of solar energy generation facilities nowadays are necessary and justified.

The popularity of photovoltaics in the energy market in Poland is growing. Its value in 2020 in Poland exceeded the level of PLN 10 billion and is constantly growing, where—according to the estimates of Distribution System Operators—the first half of 2021 resulted in 144 thousand micro-installations being built, giving an increase in the power of the total solutions of this type by 1.65 GW [43]. The total capacity of PV installations in Poland currently exceeds 6 GW (up to 50 KW), with an approximately 40% share in RES and a 3.17% [49,50] share in Poland's total volume of electricity. Especially popular in Poland are micro-installations up to 10 kWp [51]. The sinuous growth of photovoltaics in Poland (from 1.3 GW in 2019 to the planned 7 GW in 2021) has been driven by a set of government subsidies, such as:

- instruments dedicated to individuals, such as "My electricity" [52], "Clean air", "Thermomodernisation allowance".
- instruments dedicated to economic operators, such as: "Energy Plus",
- instruments dedicated to farms, such as "Agroenergy", the agricultural tax deduction for photovoltaic investments.

It is projected that the photovoltaic market in Poland will continue to grow, although the unfavorable terrain in Poland is indicated in the literature [53,54], with annual insolation of 1000 kWh/m^2 [17,55]. Therefore, especially intensive development is assumed in the segment of photovoltaic farms, which is expected to contribute to doubling the capacity of photovoltaic installations in Poland in 2024 [56]. Furthermore, promoting photovoltaic farm development programs above 1 MW contributes to their development [57,58], and energy production for companies' own needs is becoming increasingly popular in Poland [59].

The photovoltaic market in the Baltic States has not been prevalent, giving way to wind farms, especially offshore, which are strongly developing in the renewable energy sphere. However, Lithuania and Estonia's photovoltaic market development trend is beginning to gain momentum. On the other hand, Latvia is focusing its efforts on the development of alternative solutions (hydroelectric plants, wind farms). Details of the PV market in the individual Baltic States are as follows [60,61]:

(a) Lithuania:

The development of photovoltaic installations in Lithuania is of great interest to the public. The structure of solar energy installations in the country is based mainly on small installations with limited capacity, installed in the household sector. However, these installations are very numerous, and the energy obtained in this way already in 2019 assumed the level of 2.3% of the total volume of electricity production in Lithuania. In addition to small installations, Lithuania also invests in photovoltaic farms. Particularly popular are solutions to supply individual households with energy from the sun, the shares of which can be acquired by any Lithuanian, creating the dimension of "virtual prosumers". Buyers of shares corresponding to the acquisition of 2–3 KW will receive an adjustment to their electricity bills for participating in the program. The energy efficiency of such farms depends on their capacity, where, for example, for a 1 MW solution, it is about 25 GWh in 25 years.

Government instruments motivating the challenges of investing in photovoltaics are mainly financial. The targets for expanding photovoltaic capacity were reviewed this year, with 1 GW of photovoltaic capacity to be installed by 2025.

(b) Latvia:

Photovoltaics are not popular in Latvia. Of all the forms of renewable energy available, photovoltaics assume the least importance, and its share in the total volume of electricity production is about 0.1%. This situation is due to the strong development of hydroelectricity, producing about 33% of the energy produced. The lack of interest in investing in photovoltaics is due to existing formal and legal barriers and the lack of government incentives to support the activities in question. Interestingly, Latvian entities invest in PV in Lithuania and Estonia, taking advantage of support solutions in neighboring countries.

(c) Estonia:

The development of photovoltaic installations in Estonia has undergone intensive development over the past few years. It started to develop particularly strongly in 2017–2018, with an intensive increase in PV installation capacity from 11 MW, through 50 MW to 110 MW. As a result, in 2019, Estonia developed a 0.7% share of solar energy in the total volume of electricity produced, ranking 8th among EU member states with the highest per capita production of PV electricity. This action developed the target of res market development, which was assumed for 2030. The spectacular success of developing the photovoltaic market in Estonia is due to the instruments developed to support initiatives aimed at obtaining electricity based on PV solutions. These instruments included fast and transparent procedures for integrating PV installations into the grid, low equipment prices, a system of installation subsidies or financial bonuses for selling electricity to the grid. As a result, in addition to small and medium-sized installations, Estonia has begun to invest in industrial solutions in this field, including the construction of solar farms and parks.

The distribution of the share of photovoltaics in total electricity production in Poland and the Baltic States is visualized in Figure 5.

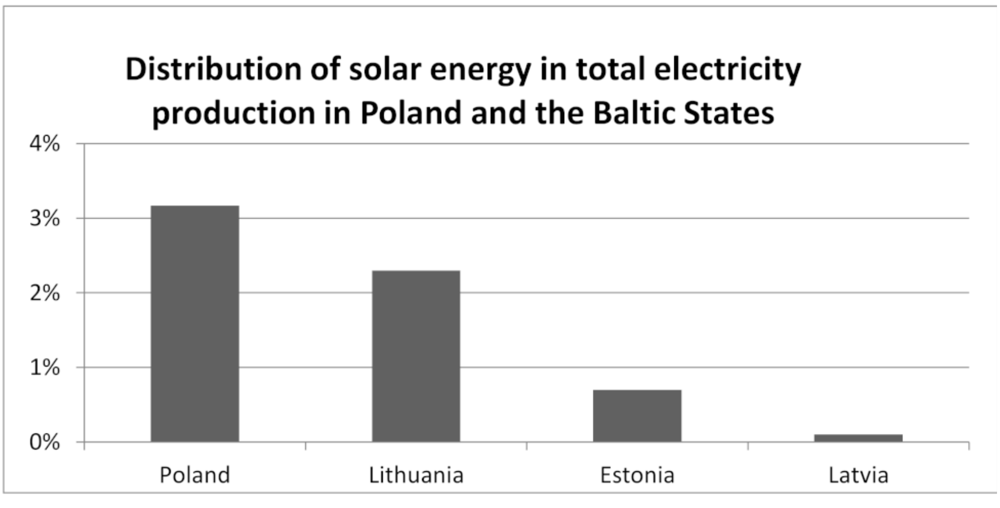

Figure 5. Distribution of the share of solar energy in the total volume of electricity production in Poland and the Baltic States [60,61].

In the examined set of countries, Poland takes the leading position with the share of 3.17% of energy from the sun in the country's total volume of electricity production. The lowest value of the share of photovoltaics in the total energy production at the economic level is generated by Latvia with a share of 0.1% of the total volume of electricity production in the country.

4.3. Photovoltaics as an Alternative Energy Source—Analysis of Market Development Trends

Photovoltaic installations contribute to reducing energy costs, so individual consumers decide to invest in green energy. However, choosing the right solution is not a simple matter. Additionally, one should remember about the right choice of power capacity because the overproduction of electricity in Poland is not economically justified [62,63].

The results of our own research "Bidding Effectiveness—Photovoltaics" (August 2021) indicate that the outlined, elementary knowledge of the photovoltaic process is critical for selecting the optimal, solutions available on the market. Analysis of the offering process (analysis of the range of offers, the level of acceptance of offers, the level of offer changes and their direction, as well as comments and opinions of the customer at the stage of offering and after-sales service), deepened with an interview with customer advisors, in a company with a significant market share in the distribution, installation, and servicing of photovoltaic installations in Poland (number of installations installed in 2020: 914), revealed that:

- Customers have relatively limited knowledge of the criteria for selecting the right ok for their energy needs, and around 80% fully accept the (technical) offer proposed by the vendor. The negotiation field is usually the price of the project.
- Purchase decisions are mainly determined (about 90%) by the price of the installation, the lifetime of photovoltaic panels (about 85%), the availability of solutions determining the time of investment implementation (about 70%), and the aesthetics of the panels (about 45%).

These studies have also revealed problems with clarifying technical uncertainties in the areas of:

- mono or polycrystalline installations—highlighting the differences in operating parameters creating the efficiency of the installation and their correlation with price,
- double-sided solutions (Bi-facial panels, drawing on bottom reflection),
- vision panels, excluding aspects of size, weight, and price.

This limits customer choice, reducing it significantly to the current (real) availability of specific assortments on the market and their price. Mass import of the most popular solutions (popularity determined by the promotion of solutions and their availability ensured by distribution points) translates into the observed mass sales in specific configurations and prices. The right choice elements of photovoltaic mounting are important in solution effectiveness and return on investment [64].

The relatively popular knowledge that the annual consumption of micro installations is in the range of 25–30% of energy paints a picture of the consumption potential of a microgrid that can include and supply energy to neighboring buildings. Interest in such a solution manifests itself in relations between buyers of photovoltaic installations and their suppliers. This topic was mentioned by approximately 20% of the customers purchasing photovoltaic installations in cooperation with the surveyed company. This shows the potential for market development, which is assumed to be more accessible for customers (financially and technically).

The analysis of the photovoltaic sector in Poland and the Baltic countries revealed the solution of "virtual prosumers", successfully practiced in Lithuania. The above inspired the authors of this paper to explore the potential for its application in Polish conditions. An interview conducted with the management of several dozen housing communities and several housing cooperatives confirms their clear interest in such a solution. The search for alternative solutions in the light of currently observed very serious increases in electricity prices strongly justifies the noted position. Participation in the photovoltaic farm with an average value of 3 KW would significantly reduce the cost of electricity purchased by households. Residents of blocks of flats would be able to enjoy the benefits of green energy more extensively than the commonly offered energy mix tariff [65] where, according to the Polish Energy Policy, a consumer of electricity who does not have photovoltaic installation benefits from a variable daily mix of energy sources, including (residually) from RES. The above may inspire the development of serious investments in Poland. Entering into participation means opening the source of investment financing, at least in part. However, what is important is the system of incentives resulting from the formal and legal framework, which determines the directions and pace of development of the RES market in Poland and other countries.

4.4. Coronavirus Pandemic and Photovoltaic Development on the Polish Market in the Baltic States

The bulk of PV panel production is carried out in the Asian market, particularly in China. This is mainly due to the key mining sites for the abovementioned raw material, silicon (P-type and N-type silicon for the construction of P-N junctions), which is critical for the most frequent use in the production of PV panel joints. However, in principle, the alternative location does not limit the need to source from the Chinese raw material, which essentially polarizes the market concerned and increases the risk of liquidity of supply from one area.

The outbreak of the coronavirus pandemic and paralysis of supplies from the Chinese market [66] had a significant impact on the photovoltaic market in Poland and the Baltic States. Furthermore, the closure of seaports and airports contributed to a lack of panels [67], which resulted in the need to postpone planned and slow down or stop ongoing investments in the construction of solar farm installations of various scales. In addition, the process of acquiring new customers was almost abandoned. The negative effects of the above situation have been reinforced in Poland by the aspect of approximately 70% dependence of the Polish market on producers from Central Countries and the limited level of diversification of the system of suppliers from outside this region.

However, the lack of market capacity did not stop Chinese production, which, once the logistic channels were opened, resulted in full availability of PV solutions and a return to a free market, almost as soon as international trade was unfrozen. Furthermore, production "on stock" contributed to maintaining prices of PV installations at essentially pre-pandemic levels, which in turn resulted in a significant increase in interest in PV solutions in the Polish and Baltic markets.

The collapse in the stability of the foreign exchange market, caused by the global crisis of pandemic-weakened economies, contributed to a significant increase in the prices of photovoltaic installation components, i.e., photovoltaic modules, inverters, inverters, etc., due to the increase in their production and acquisition costs. A noticeable increase in prices in this area has been observed since September 2021, with a significant deepening of the recorded trend occurring in November. The above is particularly reflected in the Polish market due to the highest level of depreciation of the Polish currency in many years. Lithuania, Latvia, and Estonia, which use the European currency, have not experienced such changes.

The change of the Polish currency's average exchange rate against the Baltic states' currencies is presented in Figure 6.

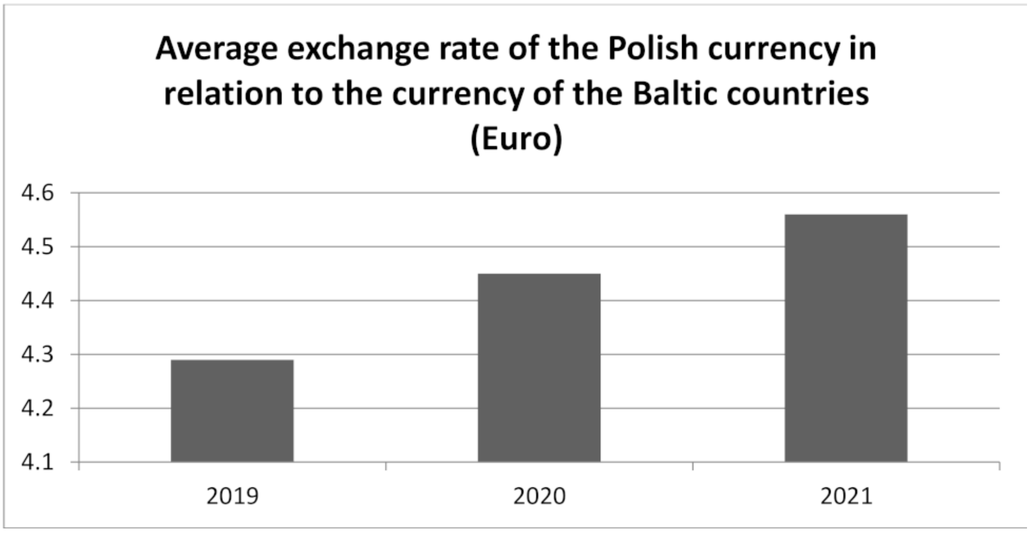

Figure 6. The change average exchange rate of the Polish currency (PLN) against the currency of the Baltic countries (Euro) in the period 1 December 2019–1 September 2021 [68].

Despite appearances, the photovoltaic market is not slowing down. On the contrary, in Poland, the opposite trend is observed. The above interest is strengthened by the announced change in legislation, according to which prosumers (producers and consumers of electricity at the same time) will be subject to different, less favorable than the current settlement rules in the mode of sale of overproduction of electricity and its "return" purchase to balance the needs [69,70].

It is difficult to estimate the strength of the photovoltaic market development in Polan once the announced regulations come into force. It is also difficult to assess the intensity of its development in the coming years in the Baltic countries. However, the demand for green energy is expected to grow [71]. The main arguments support this, i.e., the environmentally-oriented action combined with care for the community's health, juxtaposed with an equally strong economic argument—energy obtained from renewable sources is relatively cheap.

An analysis of the opinions of users of photovoltaic installations in Poland (obtained in the course of the research "Effectiveness of the offer—photovoltaics", referred to in this paper, August 2021), reveals that out of ten potential customers initially interested in photovoltaics, on average six decide to take up the challenge of purchasing photovoltaic solutions. On average, two more declare their interest in taking up such a solution in the future. Notably, four out of six customers benefiting from solutions based on this energy generation and conversion model indicate their satisfaction with the acquisition of electricity. At the same time, the remainder needs a longer perspective to assess the effects. According to the analysis of average electricity consumption loads with photovoltaic solutions, the potential for bill reduction can be generally estimated to be around 70% of their value, sometimes even 80–90% [71]. Such a range is indicated by at least half of the surveyed customers (i.e., min. 457) of the company referred to in this study, in a service interview conducted after a year of using the installation. The above research, although conducted on the Polish market, confirms the common knowledge that the key argument for electricity consumers is the price of its acquisition.

5. Discussion

The results of the considerations in this article confirm that the development of photovoltaics in Poland and the Baltic countries are the right direction to strengthen the acquisition of energy from renewable sources. However, this direction is determined by the energy policy of individual economies, which is translated into a system of regulations and incentives, directing investors to take up the challenge of building photovoltaic installations with a certain force. The above is confirmed by the policy of Poland, Estonia, and also Lithuania developing in this area. The system of incentives may be used by foreign investors, as it is noted in Lithuania and Estonia, where investments are made by entities from neighboring Latvia, stimulating the economic development of these economies. The lack of government support does not motivate investment activities in this area (Latvia). This confirms the importance of support instruments in the development of RES. However, it should be remembered that there are EU support programs for the development of the green energy market, with particular emphasis on the photovoltaic market. This form of support is used by numerous entities oriented towards developing photovoltaics.

The main participants in the photovoltaic segment of the energy markets in Poland and the Baltic States are small prosumers (owners of micro photovoltaic installations below 50 KW—producing and consuming their energy). The impulse for small investors to reach for photovoltaic solutions is, in principle, the aspect of optimizing the economic bill for electricity consumption, but in Poland, decisions in the field of photovoltaic solutions are made mainly based on suggestions from retailers. Therefore, the diagnosed state of the photovoltaic sector in Poland and the Baltic countries reveals potential for further development of the observed trends. At the same time, there is a wide perspective for the development of the photovoltaic market in the commercial dimension, which is very likely to happen soon.

The main conclusion is to confirm the economic rationale for further development of the photovoltaic sector in Poland and the Baltic countries. The justification arises against the background of energy policy, correlated with the conditions of sustainable development of individual economies and the costs of achieving the resulting objectives. Economic justification, however, should be found most strongly by the investor who undertakes the construction of photovoltaic installations, hence it is extremely important to maintain the system of incentives and intense promotion of this direction of energy acquisition. The announced unfavorable regulations in accounting for the surplus of produced energy and purchasing its shortage already this year may significantly limit this strongly developing renewable energy market in Poland.

Moreover, the "virtual prosumers" model may serve as an inspiration for strengthening the energy market development in Poland. This is an interesting direction of development of major investments, enabling the general public to take advantage of the benefits of green energy, the interest triggered mainly by the financial aspect, as well as social responsibility, in connection with strongly marked widespread environmental protection activities.

Pandemic conditions in 2020 only temporarily slowed down the development of the PV market in Poland and the Baltic States. With the opening of international exchanges, the stream of orders and installations of photovoltaic solutions has significantly increased in the area under analysis. The greatest risk of a pandemic, however, is a general weakening of economies, currency market fluctuations, and the currently observed increase in the prices of energy raw materials, determining the marked pan-European increase in wholesale electricity prices, to a significant extent still generated by conventional means (e.g., Poland). In this light, the development of RES assumes particular importance. However, the price increase also applies to components for the production of photovoltaic system accessories. This will probably not stop the observed development of the photovoltaic market in Poland and the Baltic States, but it may weaken its intensity. The above draws an interesting spectrum of further possible research.

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References

1. Magor, R. Odnawialne źródła energii w gospodarce litewskiej, Polityka Energetyczna. *Energy Policy J.* **2017**, *20*, 140.
2. Yang, L.; Wang, X.-C.; Dai, M.; Chen, B.; Qiao, Y.; Deng, H.; Zhang, D.; Zhang, Y.; Almeida, C.; Chou, A.; et al. Shifting from Fossil-Based Economy to Bio-Based Economy: Status Quo, Challenges, and Prospects. *Energy* **2021**, *228*, 120533. [CrossRef]
3. IRENA. *Renewable Power Generation Costs in 2019*; IRENA: Abu Dhabi, United Arab Emirates, 2020.
4. Golarz, M. Bezpieczeństwo energetyczne Polski na przykładzie zaopatrzenia w gaz ziemny, ropę naftową i energię elektryczną. *Bezpieczeństwo. Teor. I Prakt.* **2016**, *22*, 161–180.
5. Łukasiewicza, I. *Bezpieczeństwo Energetyczne Polski I Europy—Uwarunkowania-Wyzwania—Innowacje, Instytut Polityki Energetycznej Im*; Ruszel, M., Podmiotko, S., Eds.; Instytut Polityki Energetycznej: Rzeszów, Poland, 2019; pp. 5–8.
6. Sustainable Development Report 2019. Transformations to Achieve the Sustainable Development Goals. Available online: https://s3.amazonaws.com/sustainabledevelopment.report/2019/2019_sustainable_development_report.pdf (accessed on 5 January 2021).
7. Amri, F. Intercourse across Economic Growth, Trade and Renewable Energy Consumption in Developing and Developed Countries. *Renew. Sustain. Energy Rev.* **2017**, *69*, 527–534. [CrossRef]
8. Ben Jebli, M.; Ben Youssef, S. The Environmental Kuznets Curve, Economic Growth, Renewable and Non-Renewable Energy, and Trade in Tunisia. *Renew. Sustain. Energy Rev.* **2015**, *47*, 173–185. [CrossRef]
9. Menegaki, A.; Tiwari, A. The Index of Sustainable Economic Welfare in the Energy-Growth Nexus for American Countries. *Ecol. Indic.* **2017**, *72*, 494–509. [CrossRef]
10. Menegaki, A.N.; Tugcu, C.T. Energy Consumption and Sustainable Economic Welfare in G7 Countries; A Comparison with the Conventional Nexus. *Renew. Sustain. Energy Rev.* **2017**, *69*, 892–901. [CrossRef]
11. Slusarczyk, B.; 'Zegle ´n, P.; Kluczek, A.; Nizioł, A.; Górka, M. The Impact of Renewable Energy Sources on the Economic Growth of Poland and Sweden Considering COVID-19 Times. *Energies* **2022**, *15*, 332. [CrossRef]
12. Quitzow, R.; Bersalli, G.; Eicke, L.; Jahn, J.; Lilliestam, J.; Lira, F.; Marian, A.; Süsser, D.; Thapar, S.; Weko, S.; et al. The COVID-19 Crisis Deepens the Gulf between Leaders and Laggards in the Global Energy Transition. *Energy Res. Soc. Sci.* **2021**, *74*, 101981. [CrossRef]
13. From January, We Will Pay PLN 21 More for Electricity. Available online: https://www.ure.gov.pl/pl/urzad/informacje-ogolne/aktualnosci/9963,Od-stycznia-za-prad-zaplacimy-o-21-zl-wiecej.html (accessed on 5 January 2021).
14. Rising Energy Prices Can Have Dire Consequences-Social Unrest Threatens. Available online: https://businessinsider.com.pl/finanse/finansisci-wzrost-cen-energii-moze-miec-fatalne-skutki-groza-niepokoje-spoleczne/2hdsx0h (accessed on 5 January 2021).
15. Salim, R.A.; Rafiq, S. Why Do Some Emerging Economies Proactively Accelerate the Adoption of Renewable Energy? *Energy Econ.* **2012**, *34*, 1051–1057. [CrossRef]
16. Omri, A.; Daly, S.; Nguyen, D.K. A Robust Analysis of the Relationship between Renewable Energy Consumption and Its Main Drivers. *Appl. Econ.* **2015**, *47*, 2913–2923. [CrossRef]
17. Pestana, D.G.; Rodrigues, S.; Morgado-Dias, F. Environmental and economic analysis of solar systems in Madeira, Portugal. *Util. Policy* **2018**, *55*, 31–40. [CrossRef]
18. Peng, J.; Lu, L.; Yang, H. Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. *Renew. Sustain. Energy Rev.* **2013**, *19*, 255–274. [CrossRef]
19. Bilgili, F.; Ozturk, I. Biomass Energy and Economic Growth Nexus in G7 Countries: Evidence from Dynamic Panel Data. *Renew. Sustain. Energy Rev.* **2015**, *49*, 132–138. [CrossRef]
20. National Centre for Emissions Management. CO2, SO2, NOx, CO and Total Dust Emission Ratios for Electricity Based on the Information Contained in the National Database of Greenhouse Gas Emissions and other Substances for 2018. Available online: https://www.kobize.pl/uploads/materialy/materialy_do_pobrania/wskazniki_emisyjnosci/Wskazniki_emisyjnosci_grudzien_2019.pdf (accessed on 6 January 2022).
21. Sampaio, P.G.V.; González, M.O.A. Photovoltaic solar energy: Conceptual framework. *Renew. Sustain. Energy Rev.* **2017**, *74*, 590–601. [CrossRef]
22. Ministerstwo Gospodarki. *Polityka Energetyczna Polski Do 2030 Roku*; Ministerstwo Gospodarki: Warszawa, Poland, 2009.
23. Ministerstwo Energii. *Polityka Energetyczna Polski Do 2040 Roku*; Ministerstwo Energii: Warszawa, Poland, 2018.
24. Bhuiyan, M.A.; An, J.; Mikhaylov, A.; Moiseev, N.; Danish, M.S.S. Renewable Energy Deployment and COVID-19 Measures for Sustainable Development. *Sustainability* **2021**, *13*, 4418. [CrossRef]
25. Eroğlu, H. Effects of COVID-19 Outbreak on Environment and Renewable Energy Sector. *Environ. Dev. Sustain.* **2021**, *23*, 4782–4790. [CrossRef]
26. Available online: https://vosti.pl/aktualnosci/efekt-fotowoltaiczny-definicja-zasada-dzialania/ (accessed on 27 November 2021).
27. Frydrychowicz-Jastrzebska, G.; Bugała, A. Solar Tracking System with New Hybrid Control in Energy Production Optimization from Photovoltaic Conversion for Polish Climatic Conditions. *Energies* **2021**, *14*, 2938. [CrossRef]

28. Dobrzycki, A.; Kurz, D.; Maćkowiak, E. Influence of Selected Working Conditions on Electricity Generation in Bifacial Photovoltaic Modules in Polish Climatic Conditions. *Energies* **2021**, *14*, 4964. [CrossRef]
29. Micheli, D.; Alessandrini, S.; Radu, R.; Casula, I. Analysis of the outdoor performance and efficiency of two grid-connected photovoltaic systems in northern Italy. *Energy Convers. Manag.* **2014**, *80*, 436–445. [CrossRef]
30. Phinikarides, A.; Makrides, G.; Zinsser, B.; Schubert, M.; Georghiou, G.E. Analysis of photovoltaic system performance time series: Seasonality and performance loss. *Renew. Energy* **2015**, *77*, 51–63. [CrossRef]
31. The Largest PV Markets in the World in 2020. Available online: https://www.gramwzielone.pl/energia-sloneczna/105931/najwieksze-rynki-pv-na-swiecie-w-2020-chiny-usa-i-zaskoczenie (accessed on 5 January 2021).
32. Photovoltaics 2020 and Statistics. Available online: https://stiloenergy.pl/fotowoltaika-a-statystyki-czyli-garsc-danych-o-panelachfotowoltaicznych/?gclid=Cj0KCQiAw9qOBhC-ARIsAGrdn533_3Ch3CpyQ7o6Si7las5v-3xkzUnMgbyjznlSQD0RPTahGg66KsaArUAEALw_wcB (accessed on 5 January 2021).
33. Olczak, P.; Olek, M.; Matuszewska, D.; Dyczko, A.; Mania, T. Monofacial and Bifacial Micro PV Installation as Element of Energy Transition—The Case of Poland. *Energies* **2021**, *14*, 499. [CrossRef]
34. Jäger-Waldau, A.; Kougias, I.; Taylor, N.; Thiel, C. How photovoltaics can contribute to GHG emission reductions of 55% in the EU by 2030. *Renew. Sustain. Energy Rev.* **2020**, *126*, 109836. [CrossRef]
35. Jaeger-Waldau, A. *PV Status Report 2019*; Publications Office of the European Union: Brussels, Belgium, 2019.
36. European Commission. *A Clean Planet for All. A European Long-Term Strategic Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy*; EUR-Lex: Brussels, Belgium, 2018.
37. We Already Have 2 GW in Photovoltaics, but in Europe, We Are Still in the Second Ten. Available online: https://www.gramwzielone.pl/energia-sloneczna/103219/mamy-juz-2-gw-w-fotowoltaice-ale-w-europie-jestesmy-jeszcze-w-drugiej-dziesiatce (accessed on 6 January 2021).
38. Frankfort-Nachmias, C.; Nachmias, D. *Research methods in social sciences*; Zysk i S-ka Publishing House: Warsaw, Poland, 2001.
39. Edoo, N.; Ah King, R.T.F. Techno-Economic Analysis of Utility-Scale Solar Photovoltaic Plus Battery Power Plant. *Energies* **2021**, *14*, 8145. [CrossRef]
40. Available online: https://ec.europa.eu/eurostat (accessed on 29 November 2021).
41. Own Elaboration. Available online: https://ec.europa.eu/eurostat/documents/4187653/11581527/Evolution+of+household+electricity+and+gas+prices+in+the+EU.png/8e8a38f6-e791-ee36-c14c-844b91fad606?t=1634632173305 (accessed on 29 November 2021).
42. Available online: https://www.ure.gov.pl/pl/urzad/informacje-ogolne/aktualnosci/9964,Od-stycznia-ok-9-zlotych-wiecej-na-rachunkach-kuchenkowiczow.html (accessed on 29 November 2021).
43. Electricity Prices Continue to Rise—How to Avoid Ever-Higher Bills? Available online: https://wysokienapiecie.pl/41708-ceny-pradu-nie-przestaja-rosnac-jak-uniknac-coraz-wyzszych-rachunkow (accessed on 29 November 2021).
44. Nord Pool, Energy live, September 2021. Available online: https://wysokienapiecie.pl (accessed on 29 November 2021).
45. Own Elaboration. Available online: https://wysokienapiecie.pl/wp-content/uploads/2021/10/TGE-Wykres-Sunday-Polska.jpg (accessed on 29 November 2021).
46. Own Elaboration. Available online: https://businessinsider.com.pl/gospodarka/podwyzki-cen-pradu-w-ue-oto-co-moze-zrobic-komisja-europejska-na-rynku-energii-i-gazu/h8sw8wy (accessed on 29 November 2021).
47. Almeshaiei, E.; Al-Habaibeh, A.; Shakmak, B. Rapid evaluation of micro-scale photovoltaic solar energy systems using empirical methods combined with deep learning neural networks to support systems' manufacturers. *J. Clean. Prod.* **2020**, *244*, 118788. [CrossRef]
48. Bukowski, M.; Majewski, J.; Sobolewska, A. Macroeconomic Electric Energy Production Efficiency of Photovoltaic Panels in Single-Family Homes in Poland. *Energies* **2021**, *14*, 126. [CrossRef]
49. Installed Capacity of Photovoltaics in Poland. Available online: https://www.rynekelektryczny.pl/moc-zainstalowana-fotowoltaiki-w-polsce (accessed on 20 November 2021).
50. The Power of Photovoltaic Power Plants in Poland Exceeded 6 GW. Available online: https://www.gramwzielone.pl/energia-sloneczna/106509/moc-elektrowni-fotowoltaicznych-w-polsce-przekroczyla-6-gw (accessed on 29 November 2021).
51. Olczak, P.; Matuszewska, D.; Kryzia, D. "Mój Prąd" as an example of the photovoltaic one off grant program in Poland. *Energy Policy J.* **2020**, *23*, 123–138. [CrossRef]
52. Olczak, P.; Kryzia, D.; Matuszewska, D.; Kuta, M. "My Electricity" Program Effectiveness Supporting the Development of PV Installation in Poland. *Energies* **2021**, *14*, 231. [CrossRef]
53. Chalecka, K. *Możliwości Wykorzystania Odnawialnych Zasobów Energetycznych W POLSCE*; Acta Universitatis Nicolai Copernici: Toruń, Poland, 2010; pp. 136–137.
54. Ogarek, P. Przyszłość odnawialnych źródeł energii w Polsce w oparciu o Politykę Energetyczną Polski do 2040 roku. In *Bezpieczeństwo Energetyczne Polski I Europy—Uwarunkowania-Wyzwania—Innowacje, Instytut Polityki Energetycznej im I. Łukaszewicza*; Ruszel, M., Podmiotko, S., Eds.; Instytut Polityki Energetycznej: Rzeszów, Poland, 2019; p. 104.
55. Chwieduk, D.; Chwieduk, M. Determination of the Energy Performance of a Solar Low Energy House with Regard to Aspects of Energy Efficiency and Smartness of the House. *Energies* **2020**, *13*, 3232. [CrossRef]
56. Fotowoltaika-2021. Available online: https://enerad.pl/aktualnosci/fotowoltaika-2021/ (accessed on 28 November 2021).
57. Komorowska, A.; Kaminski, J. A review of the 2018 Polish capacity market auctions. *Energy Policy J.* **2019**, *22*, 75–88. [CrossRef]

58. Paska, J.; Surma, T.; Terlikowski, P.; Zagrajek, K. Electricity generation from renewable energy sources in Poland as a part of commitment to the polish and EU energy policy. *Energies* **2020**, *13*, 4261. [CrossRef]
59. IEO. *" isn Market in Poland 2020*; IEO: Warsaw, Poland, 2020.
60. Sun for everyone—Development of Photovoltaic Installations in the Baltic States. Available online: https://ies.lublin.pl/komentarze/slonce-dla-wszystkich-rozwoj-instalacji-fotowoltaicznych-w-panstwach-baltyckich/ (accessed on 29 November 2021).
61. Lithuanians Introduced the Concept of a Virtual Prosumer. Available online: https://www.gramwzielone.pl/energia-sloneczna/102933/litwini-wprowadzili-koncepcje-wirtualnego-prosumenta (accessed on 20 November 2021).
62. Mirowski, T.; Sornek, K. Potential of prosumer power engineering in Poland by example of micro PV installation in private construction. *Energy Policy J.* **2015**, *18*, 73–84.
63. Pepłowska, M.; Olczak, P. The tilt angle selecting problem of PV panels taking the energy demand profile into account. *Bull. Miner. Energy Econ. Res. Inst. Pol. Acad. Sci.* **2018**, *102*, 91–100.
64. Bugała, D.; Bugała, A.; Machczynski, W. Simulation of the Immunity Test of a Photovoltaic System Disturbed by Electromagnetic Voltage Surge. *Energies* **2021**, *14*, 3646. [CrossRef]
65. Szczerbowski, R. Energy security of Poland—Energy mix and energy efficiency. *Polityka Energetyczna* **2013**, *16*, 35–47.
66. Coronawirus-COVID-19. Available online: https://fotowoltaika.bruk-bet.pl/blog/nasz-wklad-w-rozwoj-branzy/koronawirus-covid19-gospodarka-rynek-fotowoltaiki/ (accessed on 29 November 2021).
67. Own Elaboration. Available online: https://www.nbp.pl/home.aspx?c=/ascx/archa.ascx (accessed on 29 November 2021).
68. Consequences of the Coronavirus Epidemic for the EU Economy. Available online: https://pism.pl/publikacje/Konsekwencje_epidemii_koronawirusa_dla_gospodarki_UE (accessed on 6 January 2022).
69. What Awaits the Photovoltaic Industry in 2022? Available online: https://www.wnp.pl/energetyka/co-czeka-branze-fotowoltaiczna-w-2022-roku,524318.html (accessed on 6 January 2022).
70. Changes in the Field of Photovoltaics from January 2022. Available online: https://fgenergy.pl/zmiany-przepisow-w-zakresie-fotowoltaiki-od-stycznia-2022-roku-lepiej-sie-pospiesz/ (accessed on 29 November 2021).
71. High Electricity Bill with Photovoltaics, What Could be the Reason? Available online: https://enerad.pl/aktualnosci/wysoki-rachunek-za-prad-przy-fotowoltaice-co-moze-byc-przyczyna/ (accessed on 29 November 2021).

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