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Law and Order for Energy Transition

Public Policies at the Crossroads

Edited by
Matheus Koengkan and Fernanda Oliveira

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About the Editors

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Preface

The global energy transition is reshaping energy production, distribution, and consumption, presenting one of today's most critical challenges. Public policies and legal frameworks play a pivotal role in guiding this shift towards sustainability. "Law and Order for Energy Transition: Public Policies at the Crossroads" explores these crucial legal aspects.

This reprint delves into the legal landscape of the energy transition, analyzing national and international frameworks, the impact of renewable energy and energy efficiency, regulatory tools, and the nexus of energy and climate policies. It addresses energy governance, the involvement of social and private sectors, and issues such as energy justice and access.

By tackling these themes, the book offers insights into the legal challenges and opportunities the global energy transition represents. It identifies barriers and proposes solutions, emphasizing integrated policy approaches and interdisciplinary dialogue among scholars, practitioners, and policymakers.

The reprint aims to deepen understanding and foster innovative thinking on the legal dimensions of the energy transition amidst climate change and dwindling traditional energy sources. It targets researchers, policymakers, practitioners, and students across law, public policy, energy studies, and related fields, aiming to promote knowledge dissemination and cross-sector collaboration.

Gratitude is extended to the peer reviewers for their valuable feedback, colleagues, and UCILeR, an R&D Unit accredited and funded by the FCT—Portugal National Agency within the scope of its strategic project, UIDB/04643/2020, for financial support, as well as to the authors for their dedicated scholarship. The reprint aspires to be a key resource for those interested in energy transition law, sparking further research and policy advancements in this critical area.

Matheus Koengkan and Fernanda Oliveira
Editors

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Article

Assessing Energy Performance Certificates for Buildings: A Fuzzy Set Qualitative Comparative Analysis (fsQCA) of Portuguese Municipalities

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Abstract: This article presents causal recipes leading to high and low energy consumption efficiency performances using fuzzy set Qualitative Comparative Analysis (fsQCA). The study found that several causal conditions are sufficient for high energy efficiency performance, including several fiscal and financial incentive policies, a highly educated population, many completed dwellings, and low GDP. The study also found that high inequality in completed dwellings and completed reconstructions, coupled with a low GDP and a low number of policies, lead to high energy consumption efficiency performance. In addition, the analysis showed slight differences between the yearly consistencies, suggesting that time effects are not a concern. On the other hand, a low education level, Gini coefficient, few completed dwellings and reconstructions, coupled with a low number of fiscal and financial policies, are the causal conditions leading to low energy consumption efficiency performance. The study's results suggest that policymakers and stakeholders should consider a combination of several causal conditions when implementing energy efficiency policies. The study also highlights the need for policies focusing on education, fiscal and financial incentives, completed dwellings, and reconstructions to achieve high energy efficiency performance.

Keywords: buildings; econometrics; economics; energy efficiency; energy performance certificates; fsQCA; Portugal; policies

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1. Introduction

Energy consumption plays a critical role in economic progress, but its excessive usage has led to greenhouse gas emissions contributing to climate change. Consequently, the European Union has implemented policies to improve energy efficiency to reduce energy consumption and Greenhouse gas (GHG) emissions. In the European Union (EU), households are the second major energy consumers, accounting for 26.3% of final energy consumption in 2019, followed by the transport sector (30.9%), industry (25.6%), services (13.7%), and agriculture and forestry (3.0%) (see Figure 1 below).

Furthermore, in the EU, final energy consumption from industry decreased by 13.0% overall between 2007 and 2019. The transport sector's energy consumption reduction was much less significant, at 0.83%, while household energy consumption decreased by 1.43%. On the other hand, the services sector experienced a notable increase in final energy consumption during the analyzed period, with an overall rise of 2.18%, as shown in Figure 2 below.

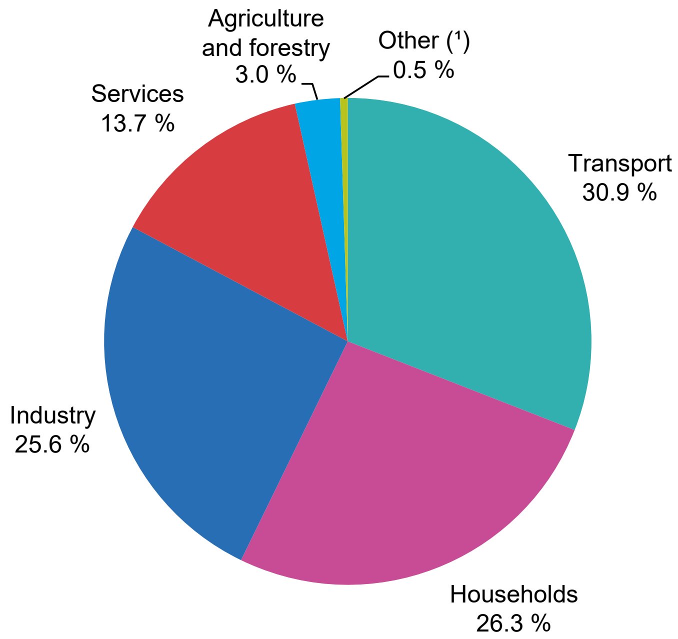

Figure 1. Final energy consumption by sector in the EU in 2019 expressed as a percentage of the total and based on tons of oil equivalent. The authors created this figure using data from Eurostat [1]. **Notes:** (1) International aviation and maritime bunkers are excluded from the Transport category.

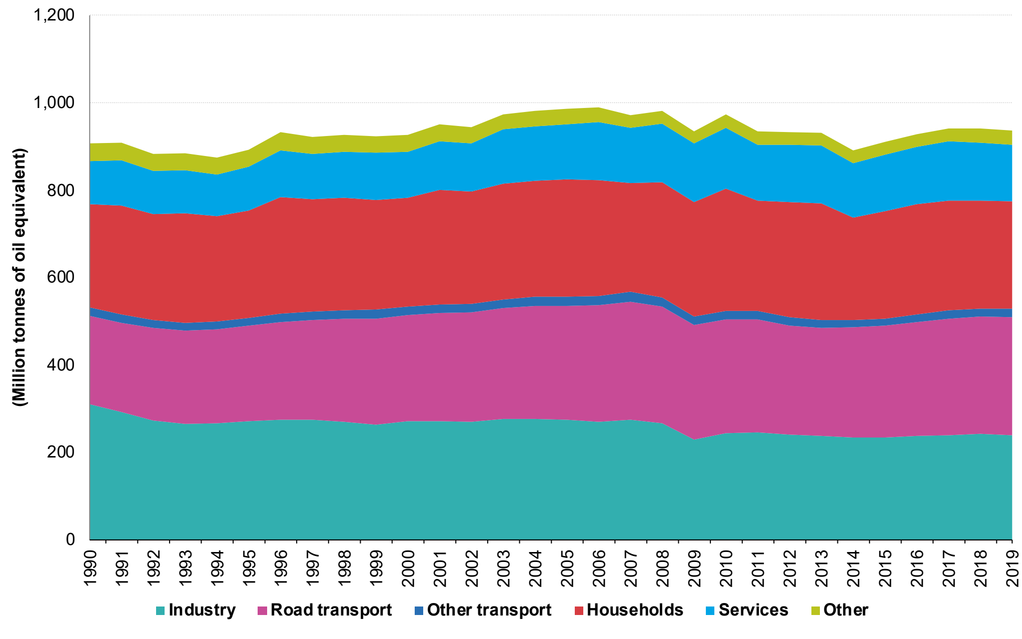

Figure 2. Final energy consumption by sector in the EU from 1990 to 2019, measured in million tons of oil equivalent. The authors created this figure using data from Eurostat [1].

Despite a lack of significant increase in recent years, the household sector still contributes to a substantial portion of total energy consumption in the EU, accounting for 40% of the total. Moreover, this sector is also responsible for 1/3 of GHG emissions and 36% of CO_2 emissions, which contribute to climate change. Energy consumption from the residential sector is the primary contributor to this issue. As Palma et al. [2] noted, various factors influence energy consumption in this sector, making it a complex issue.

Compared to other sectors, the residential sector has made significant progress in energy efficiency thanks to implementing various EU policies. These policies aim to reduce energy consumption and mitigate climate change through cost-effective energy efficiency measures. One such measure is the energy performance guideline for buildings, which includes using energy performance certificates (EPCs) to analyze the energy performance of residential buildings. This initiative has been studied extensively by researchers such as Palma et al. [2], Pablo-Romero et al. [3], Ramos et al. [4], Lee et al. [5], and Abela et al. [6].

The European Union (EU) has implemented a range of policies to improve the energy performance of buildings and reduce energy consumption. One such policy is the energy performance of buildings directive (EPBD) (Directive 2002/91/EU), which was introduced in 2002 and implemented in January 2006. The EPBD focused on minimum energy performance requirements and the inspection of boilers and air conditioning systems [7]. Another policy was the energy performance certificates (EPCs), introduced with Directive (2010/31/EU) in 2010. This policy was the primary EU instrument to improve the energy performance of buildings while considering cost-effectiveness and local conditions and requirements. The implementation of EPCs gradually varied by Member State or region [7,8]. In 2012, Directive (2012/27/EU) updated the goals set by Directive (2010/31/EU) for the years 2020 and 2030, with a 20% and 30% reduction in energy consumption, respectively. Finally, the Directive (2018/844/EU) aimed to accelerate the cost-effective renovation of existing buildings and achieve the goal of a decarbonized building stock by 2050 [9].

Energy performance certificates (EPCs) are tools to evaluate the energy efficiency of buildings and offer recommendations to improve their rating cost-effectively [8]. Typically, EPCs in the EU use a letter scale from A to G, where A represents the highest energy efficiency and G is the lowest [7]. However, in Portugal, the scale ranges from A to F [10]. These guidelines aim to increase transparency and reduce information asymmetry regarding the energy performance of residential units, with the ultimate objective of enhancing energy efficiency and lowering energy consumption in buildings [11].

Providing energy performance certificates (EPCs) to potential buyers and tenants when selling or renting residential units promotes transparency about the energy efficiency of the building and allows for easy access to reliable information [5,12–14].

This circumstance can encourage building owners to renovate their properties for improved energy efficiency, as buildings with higher EPC ratings typically have higher prices [15–17]. Furthermore, upgrading a building's energy efficiency can reduce energy consumption by up to 46% [18]. The EPC process promotes energy savings and reduces overall energy consumption by incentivizing building owners to improve their EPC rating.

The implementation of energy performance certification across the EU varies depending on the local political and legal context, financial incentives, and the characteristics of the local property market [7]. Countries and regions have different timelines for adopting EPC legislation in buildings, with some making it mandatory earlier than others. For example, Belgium made it mandatory for all buildings (new and existing) in 2006, while England and Wales followed in 2008, and Austria in an unspecified year. Ireland and Portugal made it mandatory in 2009, and Cyprus and France in 2010 [7].

Regarding Portugal, the subject of our investigation, all new buildings since July 2008 must possess a valid energy performance certificate, while existing buildings have had one since 2009. With the introduction of Decree-Law no. 118/2013 in Portugal, which follows Directive (2010/31/EU), the EPC became mandatory when signing the sale, rental, or lease contract. The number of certificates issued in Portugal was 13,798 in 2008, which more than doubled in 2009, reaching 188,716 certificates. However, the count declined significantly between 2011 and 2013, bottoming at 74,969 in 2013. It can be attributed to the financial and economic crisis that affected Portugal as one of the hardest-hit countries in the EU. Nevertheless, the number of new certificates recorded has increased since 2014, and in 2020, 198,091 certificates were issued (see Figure 3 below).

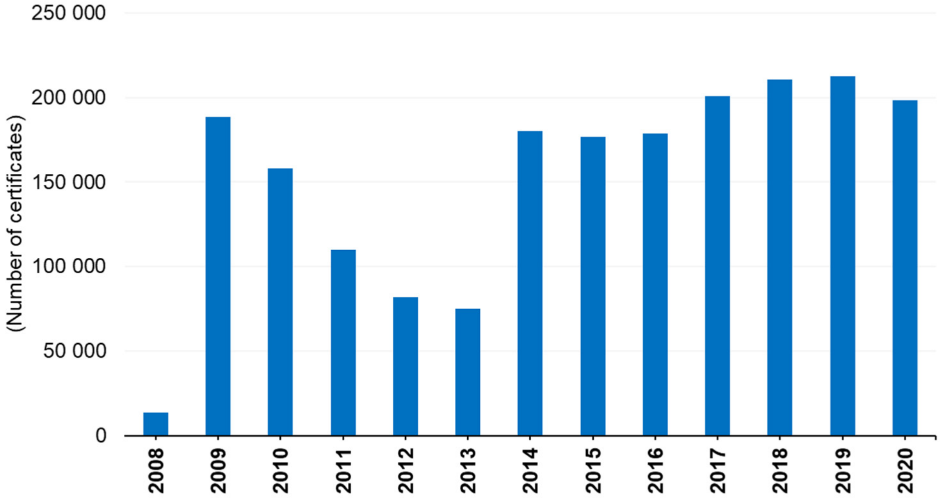

Figure 3. Energy performance certificates issued in Portugal during 2008–2020. The authors created this figure with data from *Observatório da Energia* [19]. **Notes:** During 2008–2013, they included A+, A, B, B-, C, D, E, F, and G certificates, while during 2014–2020, they included the A+, A, B, B-, C, D, E, and F certificates. The EPC with rating G was discontinued in 2014.

Looking at the number of energy certificates issued in Portugal, we can see that in 2008, the most commonly issued certificates were for ratings B and B+. There were 4165 and 1635 certificates issued for these ratings, respectively, while ratings C, D, E, F, and G had much lower numbers, with only 141, 75, 14, 4, and 11 certificates issued, respectively. In 2014, ratings C and D had the most certificates issued, with 58,209 and 46,661 certificates, respectively. There were also 1893 certificates issued for rating A+, 7018 for rating A, 12,951 for rating B, 19,171 for rating B-, 24,379 for rating E, and 9758 for rating F. Moving forward to 2020. The most frequently issued certificates were for ratings C and D, with 41,347 and 34,961 certificates issued, respectively. In addition, there were 31,186 certificates issued for rating B, 20,156 for rating B-, 21,721 for rating E, and 12,934 for rating F. It is worth noting that the data presented for 2008 to 2013 covers certificates with ratings A+, A, B, B-, C, D, E, F, and G, while the data presented for 2014 to 2020 only includes certificates with ratings A+, A, B, B-, C, D, E, and F. It is also important to note that the EPC with a rating of G was discontinued in 2014 (See Figure 4 below).

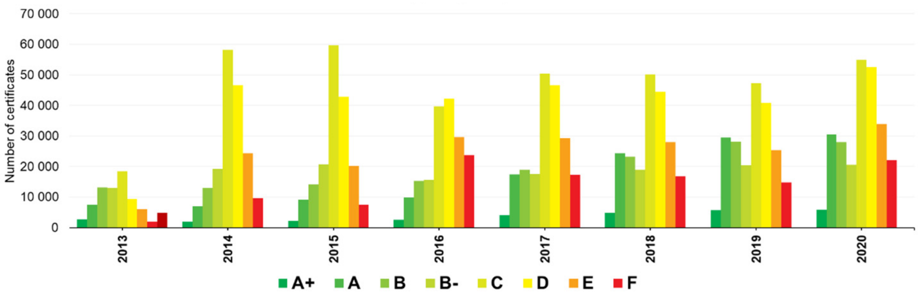

Figure 4. Energy performance certificates by energy class issued in Portugal during 2008–2020. The authors created this figure with data from *Observatório da Energia* [19]. Notes: During 2008–2013, they included A+, A, B, B-, C, D, E, F, and G certificates, while during 2014–2020, they included A+, A, B, B-, C, D, E, and F certificates. The EPC with rating G was discontinued in 2014.

Increasing the number of energy certificates with high ratings such as A+, A, B, and B- is important for Portugal to reduce household energy consumption. The household sector accounted for 18.2% of total energy consumption in 2019 (see Figure 5 below).

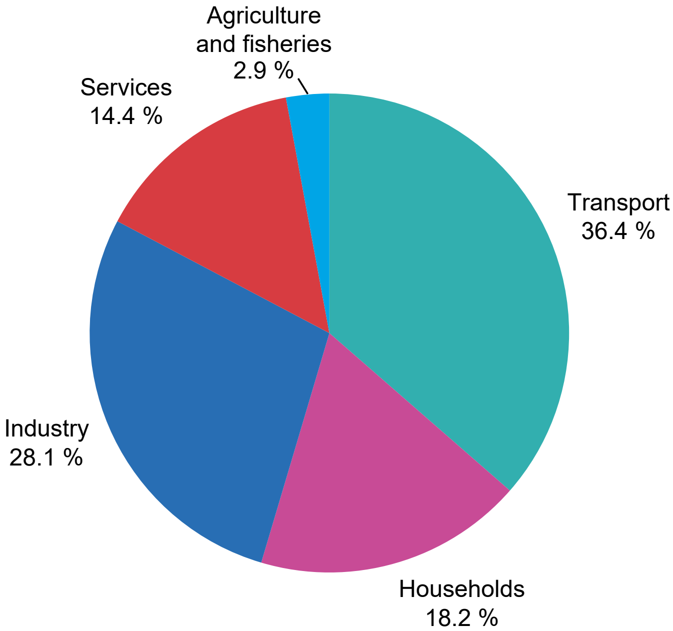

Figure 5. Final energy consumption by sector in Portugal in 2019, expressed as a percentage of the total and based on tons of oil equivalent. The authors created this figure using data from PORDATA [20].

It increased from 2301.6 Mtoe in 1990 to 2820.9 Mtoe in 2000 and 2891.3 Mtoe in 2019. However, due to financial and economic crises, household energy consumption decreased by 6.52% in 2011, 3.05% in 2012, and 2.29% in 2013 (See Figure 6 below).

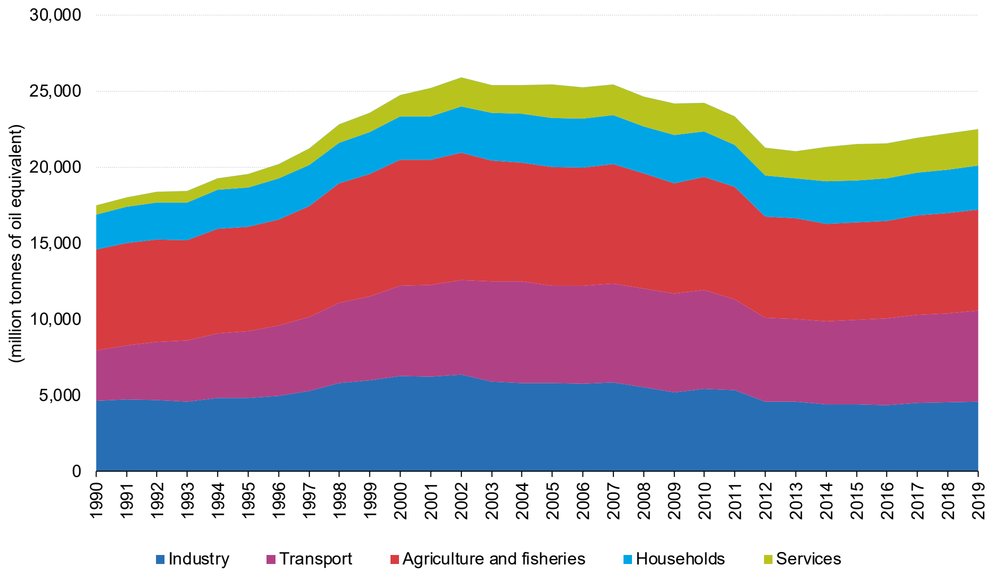

Figure 6. Final energy consumption by sector in Portugal from 1990 to 2019, measured in million tons of oil equivalent. The authors created this figure using data from Eurostat [1].

The distribution of gross inland energy consumption in Portugal significantly differs from the EU average. In 2019, oil and petroleum products accounted for 42.6% of the energy mix, while solid fossil fuels represented 11.3%, natural gas 21%, and renewables and biofuels 25.2%. In contrast, the EU consumed 34% oil and petroleum products, 11.6% solid fossil fuels, 23.1% natural gas, and 15.8% renewables and biofuels in the same period, according to Eurostat (2023).

Promoting the use of Energy Performance Certificates (EPCs) is crucial to reduce the impact of fossil fuels on the environment and lower household energy consumption in Portugal. As shown in the previous chart (Figure 6 above), in 2019, fossil fuels represented the majority of the energy mix in Portugal, totaling 74.9%.

After observing an increase in the number of new energy performance certificates (EPCs) registered in Portugal, the question arises: What factors influence the adoption of EPCs with high or low energy consumption performance? Surprisingly, the literature does not explore the determinants of EPC adoption in Portugal or other countries. However, existing literature has focused on the factors that determine increased energy efficiency in residential buildings, such as mandatory legislation for energy performance certification, concerns about energy consumption, prices, and the environment, transaction prices and rents, the existence of fiscal and financial/incentive policies, social and economic aspects, and characteristics of proprieties. It is important to note that enhancing energy efficiency in buildings will undoubtedly impact energy efficiency ratings.

Conducting this study has become essential to address the gap in the literature regarding the determinants of EPCs with high or low energy consumption performance adoption in Portugal. Therefore, the main objective of this investigation was to study the determinants of EPCs with high or low energy consumption performance adoption in Portugal. An empirical analysis of 308 municipalities in Portugal from 2015 to 2019 was conducted to accomplish this study. The methodological approach used in this investigation was the fuzzy set Qualitative Comparative Analysis (fsQCA), which aims to identify the combinations of causal conditions sufficient for high or low energy consumption efficiency performance.

This study has several important features, including its relevance, innovation, and potential contributions. This investigation is important because it attempts to fill the gap in the literature regarding the determinants of EPCs with high or low energy consumption performance adoption in Portugal. Therefore, this study is relevant for policymakers, researchers, and stakeholders interested in promoting energy efficiency and reducing carbon emissions in Portugal.

In addition to its relevance, this study is innovative in using the fuzzy set Qualitative Comparative Analysis (fsQCA) methodological approach. This approach allows for identifying the combinations of causal conditions sufficient for high or low energy consumption efficiency performance, providing a more nuanced understanding of the determinants of EPC adoption. This innovative approach can potentially contribute to the broader literature on energy efficiency and EPC adoption.

The potential contributions of this study are significant. On the one hand, it can provide valuable information for policymakers and stakeholders interested in promoting energy efficiency in Portugal. On the other hand, it can contribute to the broader literature on energy efficiency and EPC adoption by providing empirical evidence from a new context and using an innovative methodological approach. This study's findings have the potential to inform the development of more effective policies and programs aimed at promoting energy efficiency in Portugal and beyond.

Expectations for this study include the identification of key determinants of EPC adoption in Portugal and a better understanding of the relationships between these determinants. This study's findings may also highlight areas where further research is needed to understand better the factors that influence EPC adoption in Portugal and other contexts. Overall, this study has the potential to significantly contribute to the literature on energy efficiency and EPC adoption, and its findings could have practical implications for policymakers and stakeholders interested in promoting energy efficiency and reducing carbon emissions.

This study is structured as follows: Section 2 is a literature review, providing an overview of existing research on the subject. Section 3 outlines the data and methodology used in this study. Section 4 presents the results of the analysis. Finally, Section 5 provides the study's conclusions and policy recommendations.

2. Literature Review

The literature does not adequately examine the determinants of household adoption of EPCs with high or low energy consumption performance. To overcome this limitation, we have relied on literature that closely relates to this topic. Therefore, this section will focus on the main literature that addresses the determinants of energy efficiency in residential buildings. Some authors, including Trotta et al. [8], and Mudgal et al. [7], suggest that the increase in energy efficiency performance in residential buildings is related to mandatory legislation of energy performance certification, concerns about energy consumption, energy prices, and the environment, as well as transaction prices and rents. Other authors, such as Trotta et al. [8], Noailly [9], Sarker et al. [21], and Filippini et al. [22] have pointed out that this increase is related to fiscal and financial incentive policies. Some authors, such as Lakić et al. [23], Gómez-Román et al. [24], and Trotta [25], indicated that social-economic aspects can promote energy efficiency initiatives. Moreover, others, such as McCord et al. [26], argued that properties' characteristics determine specific energy efficiency levels.

This literature review will be structured around the following topics: (Section 2.1) Legal obligation; (Section 2.2) Concerns about energy consumption, prices, and the environment; (Section 2.3) Concerns about transaction prices and rents; (Section 2.4) Existence of fiscal and financial incentive policies; (Section 2.5) Social-economic aspects; and (Section 2.6) Characteristics of proprieties. By examining these topics, we can better understand the determinants of household adoption of EPCs with high or low energy consumption performance and identify the factors that promote or hinder energy efficiency initiatives in the residential building sector.

2.1. Legal Obligation

According to Reed et al. [27], the use of rating tools for buildings began in 1990 in the UK with the introduction of the Building Research Establishment Environmental Assessment Method (BREEAM), a multi-criteria tool. Several other rating schemes have followed in different jurisdictions, some focusing on energy while others taking a broader sustainability approach [28]. For example, Energy Star (energy) in the US, the French HQE scheme (multi-criteria), and the Swiss Minergie (energy) label were all introduced in the 1990s. In the 2000s, various multi-criteria schemes like the Leadership in Energy and Environmental Design (LEED) in the US, Green Globe in Canada, Green Star in Australia, and Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in Japan were launched [7]. The EU framework for energy performance labelling of buildings was a relatively late starter, starting in 2002 [7].

Trotta et al. [8] pointed out that dwelling and energy-related product standards aim to ensure efficient energy performance for buildings, heating equipment, and building components. Even if purchasers lack the motivation or credit to purchase more efficient products, these standards ensure that energy-efficient products are available. Furthermore, Noailly [9] stated that mandatory energy efficiency standards are one of the main drivers of innovation. In the EU, mandatory energy efficiency standards are the preferred policy option to address obstacles to energy efficiency, as per Bleischwitz et al. [29].

The EU began implementing energy efficiency standards in 2002 by introducing the Energy Performance of Buildings Directive (EPBD) (Directive 2002/91/EU). This policy instrument focused on improving the minimum energy performance requirements and inspections of boilers and air conditioning systems, and it came into force in January 2006 [7]. Energy Performance Certifications (EPCs) were gradually introduced in different Member States or regions through Directive (2010/31/EU) in 2010, which was the primary EU policy instrument to improve the energy performance of buildings. This directive aimed to consider cost-effectiveness, local conditions, and requirements, given that energy consumption in buildings is highly influenced by local climates and cultures [7,8]. Directive (2012/27/EU) updated Directive (2010/31/EU) and set goals for reducing energy consumption by 20% and 30% by 2020 and 2030, respectively [9]. The most recent update was made with the introduction of Directive (2018/844/EU), which aims to accelerate the cost-effective renovation of existing buildings and achieve a decarbonized building stock by 2050.

The EPCs are a crucial tool for improving the energy efficiency of buildings, as they are part of the EPBD, as noted by Mudgal et al. [7]. Trotta et al. [8] explained that these certificates evaluate a property's energy efficiency and suggest cost-effective enhancements to increase the building's rating. Most countries use a letter-based rating system (such as A to G), where A is very efficient, and G is very inefficient, but Portugal uses a different letter scale (A to F), as per SCE [10]. Additionally, for existing buildings, the EPC may show the potential rating (with possible improvements), the current rating, and a benchmark for an average-performing building, according to Mudgal et al. [7].

Furthermore, according to Trotta et al. [8], the EPCs are an important tool for consumers to learn about the energy consumption of the property they wish to purchase or rent and are mandatory in EU countries in case of a change of occupant or sale. Although new buildings can be designed to be highly efficient, the current stock of buildings is predominantly of poor energy performance. This situation is because these were primarily built before energy use regulations were introduced and when there were varying expectations for thermal comfort. In addition, building components and technical systems are subject to wear and tear over time, leading to increased energy consumption to provide the same level of energy service.

The way energy performance certification is implemented and its effectiveness varies across the EU-27, depending on different factors like the local legal and political context and the specific characteristics of the property market in the area [7]. For instance, it became mandatory to adopt EPC legislation in all buildings (new and existing, and to sell or rent) in Belgium in 2006, in England and Wales in 2008, and in Austria in 2008. In Ireland and Portugal, it became mandatory in 2009, while in Cyprus and France, it became mandatory in 2010 [7].

Although the impact of mandatory energy policies on EPCs has not been explored in the literature, we have opted to use literature closely related to this topic. Therefore, we will use literature that explores the effect of mandatory energy efficiency policies on energy efficiency in buildings. For instance, Jonkutė et al. [30] investigated the impact of mandatory energy performance certification on CO_2 emissions in residential buildings in Lithuania. The authors conducted an empirical analysis of data collected in 2014, and the results showed that EPCs mitigate CO_2 emissions. Furthermore, the reduction in emissions was caused by increased energy efficiency due to EPCs, reducing energy consumption from non-renewable energy sources.

Thonipara et al. [31] studied the impact of regulatory policies on the energy efficiency of residential buildings in the EU. The authors carried out an empirical analysis of data collected from 28 EU countries for the period 2000–2015. The findings showed that building regulations could effectively reduce energy consumption in residential buildings. However, it may take some time before the impact of regulatory standards for new buildings and significant renovations becomes noticeable. Trotta [25] conducted a study on the factors that affect energy-efficient retrofit investments in the residential sector in England. The author analyzed data from 1990, and the results showed that retrofit measures could significantly decrease energy demand, particularly for space heating, and subsequently lower associated CO_2 emissions.

Furthermore, several authors have also investigated the impact of mandatory energy efficiency policies on buildings' energy efficiency, including Mudgal et al. [7], Trotta et al. [8], Filippini et al. [22], Broin et al. [32], and Vine et al. [33].Thus, it can be observed that mandatory energy performance policies for buildings are the primary drivers that motivate consumers and property owners to improve energy efficiency in their homes by reducing energy consumption. Additionally, energy performance ratings reflect the enhancement of energy efficiency in houses.

2.2. Concerns about Energy Consumption, Prices, and the Environment

Concerns regarding energy consumption and environmental impact can influence consumer decisions regarding adopting energy performance certificates in the EU [7]. Indeed, these two concerns may be related to the consumer's mind [34]. For example, Mudgal et al. [7] found that consumers consider information about a property's energy performance when purchasing or renting. Furthermore, the concern about building energy use is the main factor influencing consumers at the moment of the decision since energy use has a positive link with the environment. This situation means that consumers are worried about the type of energy source (e.g., renewable or non-renewable) used in their residences, and an increase in consumption leads to an increase in environmental degradation due to CO_2 emissions.

The concerns regarding climate change reflect the views of many Europeans. According to the European Commission [35], almost one-third of Europeans, 28%, consider climate change the most pressing global issue. Furthermore, many individuals have taken measures to control and reduce energy consumption in their homes. Among those measures are using smart meters 10%, installing solar panels 8%, switching to energy suppliers that offer more renewable sources 10%, improving home insulation 18%, and buying low-energy consumption homes 4%.

There is a significant variation in the attitudes and concerns toward energy consumption and the environment among EU countries (see Table 1, below). Indeed, this table below was created with data from European Commission [35].

Table 1. Attitudes and concerns toward energy consumption and the environment among EU countries.

Attitudes and Concerns	Germany	France	Ireland	Spain	Portugal
Climate change as the most important global issue	18%				
Installed equipment to reduce energy consumption	10%	14%	21%	2%	16%
Installed solar panels	9%	3%	11%	3%	17%
Switched to a supplier with a higher share of renewable energy	17%	10%	23%	2%	11%
Improved their home insulation	16%	22%	37%	9%	29%
Bought a low-energy home	3%	4%	5%	1%	6%

Notes: This table was created by the authors with data from European Commission [35].

Therefore, we can consider Europeans in favor of the environment. According to Gómez-Román et al. [24] and Gardner and Stern [36], the BWES covers an individual's willingness to take energy-efficient measures, such as investments in lower energy use or energy curtailment measures, like reducing the use of air conditioning, watching television, or charging electronic devices.

According to Mills and Schleich [37], the BWES could be related to socio-economic aspects. For example, family age-composition patterns distinctly impact household energy use behavior. Families with young children have a higher tendency to embrace energy-saving technologies and eco-friendly habits while concentrating on energy conservation to protect the environment. Conversely, households with a substantial number of elderly individuals prioritize financial savings. As a result, they typically have lower rates of technology adoption and a reduced understanding of household energy use and energy-saving practices, such as turning off lights or utilizing energy-efficient light bulbs. Moreover, individuals with higher levels of education place greater importance on energy savings for environmental reasons and less on financial savings.

Additionally, Poortinga and colleagues [38] argued that actions that indirectly affect the environment can shape the political environment in which people make decisions related to environmental concerns. For example, engaging in environmental activism and supporting sustainability policies can create a more supportive context for making environmentally conscious choices. Another factor related to energy consumption that leads consumers to invest in energy-efficient retrofits and obtain energy performance certificates is the high price of electricity, which has been increasing in recent years [39]. Indeed, Lainé [40] pointed out that consumers place little importance on energy efficiency when they are highly concerned about their energy bills. The same author also noted that adopting energy certificates in the United Kingdom is related to significant concerns about household energy bills. The Mudgal et al. [7] and ERA [41] stated that energy performance certificates have gained significance due to buyers' growing awareness of energy expenses and consumption levels, especially for mid-price assets.

The impact of energy consumption, prices, and environmental concerns on adopting EPCs with high or low energy performance in the literature has not been extensively studied. Therefore, we decided to focus on authors investigating the effect of energy consumption, energy prices, and environmental concerns on household energy efficiency.

A study by Lakić et al. [23] investigated the key attributes that Slovenians consider when buying a highly energy-efficient property and investing in more efficient heating controls. The research showed that energy efficiency was the second most critical factor after property price. The study found that individuals who were environmentally conscious, married, or female were more likely to appreciate energy efficiency. The research also found that women preferred shorter payback periods, while people with higher education valued future costs more and were willing to invest more in energy efficiency. Homeowners who were concerned about climate change were also found to be more likely to value energy efficiency.

Similarly, CONSEED [42], Pelenur [43], and Frederiks et al. [44] found that households worried about climate change were more inclined to value energy efficiency. However, these incentives for energy-efficient measures were primarily targeted at environmentally conscious homebuyers. Other authors, such as Mudgal et al. [7], Gómez-Román et al. [24], Gardner and Stern [36], Mills and Schleich [37], Poortinga et al. [38], Nair et al. [39], Ferrantelli and Kurnitsk [45], Belaïd et al. [46], and Stern [47], have also investigated the effect of energy consumption, prices, and environmental concerns on energy efficiency in households.

It can be observed that concerns about energy consumption in favor of the environment and energy prices are among the determinants that lead households to adopt energy efficiency technologies and conservation practices. This adoption, in turn, impacts the energy efficiency ratings of buildings.

2.3. Concerns about Transaction Prices and Rents

Concerns about transaction prices and rents also drive the adoption of energy performance certificates. Mudgal et al. [7] stated that environmental and energy labelling schemes make a product's energy performance visible, which would not be easily visible otherwise. Therefore, without information from sellers about a property's energy performance, the value of a well-insulated building would not be reflected in the transaction price or rent. This lack of transparency may discourage owners from making energy-saving improvements, particularly if they plan to sell or rent their property in the short term.

The concept that products can be understood as a bundle of characteristics, as proposed by Lancaster [48], supports the idea that some characteristics are more visible than others. Mudgal et al. [7] argued that environmental and energy labelling schemes make it possible for buyers to consider a product's energy performance, which would otherwise be difficult to compare. However, this information can only impact the market if energy performance is deemed important by buyers/renters or if sellers/landlords anticipate its growing importance and choose to make energy efficiency a salient attribute. Mudgal et al. [7] further suggested that energy and other environmental labelling schemes are necessary for energy-efficient products to receive due recognition in the market, as they provide the basic conditions for buyers/renters to consider this product dimension.

Mudgal et al. [7] argued that constructing buildings with better energy performance is more expensive, and it is important to determine if the extra cost is justifiable and if it results in any additional returns for the investor. This argument also holds when renovating existing buildings. Hence, the authors suggested that it is worth exploring whether buyers are willing to pay a premium for buildings with better energy performance, irrespective of whether they are more costly to build. Additionally, buildings with better energy performance may retain their value better in changing demands and regulatory requirements, making them more future-proof.

Ürge-Vorsatz et al. [49] conducted a review which suggests that the energy performance of buildings impacts their value due to the savings it can generate and the increasing awareness of environmental concerns. Additionally, energy-efficient buildings are expected to have higher monetary value because they offer more benefits than less efficient buildings, such as better services. According to Mudgal et al. [7], energy performance affects the cost of providing a certain level of services. If two properties offer similar services but have different running costs, the price of living in these properties should reflect that difference. Therefore, the net present value of goods providing the same utility to consumers should be equalized. As a result, the price of two goods providing the same services but with different energy efficiency levels should not be the same.

Mudgal et al. [7] examined the relationship between energy performance certificates (EPCs) and European transaction prices and rents. They found that improvements in a property's energy efficiency were associated with higher prices and rents in several countries. For example, in Austria, a one-letter improvement in energy efficiency was linked to an 8% increase in sales prices and a 4.4% increase in rental prices. In Belgium, EPCs significantly impacted property prices and rents, with a clear relationship between a property's energy efficiency and the advertised price or rent. Improvements in energy efficiency were associated with a 4.3% higher price and a 3.2% higher rent. Similarly, a one-letter improvement in a property's energy label corresponded to a 4.3% higher price in France. Finally, in Ireland, there were indications that energy efficiency was rewarded in the property market, with a one-letter improvement in energy efficiency resulting in a 2.8% increase in sales prices and a 1.4% increase in rental prices.

While limited literature explores the impact of transaction prices and rents on energy performance certificates (EPCs), we can draw insights from related studies. Barreca et al. [50] analyzed data on Turin's Italian real estate market, investigating the influence of EPC labels and building features on housing prices between 1946 and 1990. Their findings suggest that EPC labels are gaining influence in shaping price dynamics, with low EPCs (E, F, and G) having a significantly negative impact on prices and high EPCs (A1, A2, A3, A4, and B) having a slightly positive effect. Intrinsic building characteristics such as building category and housing unit maintenance level also emerged as influential factors in property price formation.

An investigation on the impact of energy performance certificates (EPCs) on the rental market in Norway was conducted by Khazal and Sønstebø [51]. The authors utilized data collected for the period 2011 to 2018 to determine whether labelled dwellings had a premium compared to non-labelled ones. The results indicated that labelled dwellings had a premium, which increased with a higher EPC label.

According to McCord et al. [26], a study was conducted to evaluate the impact of EPCs on house prices in the Belfast housing market, Northern Ireland. The authors used data collected from Q2 2018 to Q1 2019 and assessed the effects of standardized cost-effective retrofit improvements. The results suggest that EPCs have differential valuations across the quantiles, with only upper quantiles of the price distribution showing significant capitalization effects with energy performance. Additionally, only properties with higher EPC scores significantly positively affect prices at the higher end of the price distribution, with brown discount effects observed for lower-rated properties within F- and G-rated EPC properties at the higher end of the pricing distribution. Furthermore, the potential energy efficiency rating also shows increased sales prices and appears to minimize any brown discount effects.

Additionally, several studies have examined the relationship between EPCs and transaction prices and rents, including works by Mudgal et al. [7], McCord et al. [52], Cespedes-Lopez et al. [53], Chegut et al. [54], Wilhelmsson [55], Graaf [56], Cerin et al. [57], Högberg [58], and Fuerst and McAllister [59]. However, this literature review highlights the lack of consensus regarding the impact of EPCs on transaction prices and rents. While some authors suggest that EPCs lead to an increase in transaction prices and rents (e.g., Mudgal et al. [7]; McCord et al. [26]; Barreca et al. [50]; Khazal and Sønstebø, [51]; Chegut et al. [54]; Graaf, [56]; Cerin et al. [57]; and Högberg [58]), others suggest that they have no effect (e.g., McCord et al. [52]; Cespedes-Lopez et al. [53]; Chegut et al. [54]; Wilhelmsson [55]; and Fuerst and McAllister [59]).

2.4. Existence of Fiscal and Financial Incentive Policies

Various policies providing fiscal and financial incentives can significantly promote households' adoption of Energy Performance Certificates (EPCs) in buildings. Studies conducted by researchers such as Trotta et al. [8], Noailly [9], Sarker et al. [21], and Filippini et al. [22] have suggested that incentives in the form of financial and credit rewards encourage individuals to improve energy efficiency.

According to Sarker et al. [21], fiscal incentives are essential in promoting building energy efficiency. Such incentives, often provided via a country's tax system, offer tax subsidies, rebates, and tax holidays for investments in energy-efficient technologies. Moreover, financial incentives are also available to homeowners contemplating energy efficiency refurbishment, including roof insulation, walls, recuperative ventilation, and investments in green energy sources [23].

The literature lacks research on the influence of fiscal and financial incentive policies on Energy Performance Certificates (EPCs) with varying levels of energy performance. Therefore, we relied on literature that is closely related to this topic. This literature review focuses on authors who have explored the impact of fiscal and financial incentive policies on energy efficiency in buildings. Several studies have investigated this relationship. For instance, He and Chen [60] studied the effect of different government subsidy policies on green buildings. They examined four subsidy policies: subsidies to developers only, subsidies to consumers only, subsidies to both, and non-payment of subsidies. Their results revealed that subsidies positively impact the development of green buildings. Furthermore, simultaneous subsidies to developers and consumers yielded the most significant benefits for developers and the highest social welfare.

Villca-Pozo and Gonzales-Bustos [61] studied the effect of tax incentives to improve the energy efficiency of Spanish households. The study conducted by the authors examined data collected for the period 2009 to 2018 and revealed that tax benefits alone are insufficient to promote energy efficiency. However, the authors suggested utilizing the fiscal route to encourage home energy efficiency. Finally, Trotta et al. [8] investigated the effectiveness of policy instruments and private initiatives in selected European countries, such as Finland, Italy, Hungary, Spain, and the United Kingdom. The authors analyzed policy instruments implemented in these countries between 1990 and 2015. The findings indicated that financial facilities, including grants, subsidies, soft loans, etc., and fiscal incentives indirectly reduce the cost of investments and incentivize building energy efficiency.

In a study by Bonifaci and Copiello [62], tax incentive policies for enhancing energy resilience in residential buildings in Italy were evaluated. The authors analyzed data from 2010 and found that the tax incentive policies failed to stimulate an increase in the minimum energy standards in residential buildings. Moreover, other authors have also explored the effects of fiscal and financial incentive policies on EPCs (e.g., Filippini et al. [22]; Ferrantelli et al. [63]; Neveu and Sherlock [64]; Ameer and Krarti, [65]; Shen et al. [66]; Chen and Hong [67]; Alberini and Bigano [68]; Charlier [69]; and Dubois and Allacker, [70]).

This literature review highlights the lack of consensus regarding the influence of fiscal and financial incentive policies on building energy efficiency. While some authors suggest that these policies have a positive impact on Energy Performance Certificates (EPCs), others do not share the same view (e.g., Trotta et al. [8]; Filippini et al. [22]; He and Chen [60];Neveu and Sherlock, [64]; Ameer and Krarti [65]; and Chen and Hong [67]). At the same time, others have indicated that fiscal and financial incentive policies do not have any impact (e.g., Villca-Pozo and Gonzales-Bustos [61]; Bonifaci and Copiello [62]; Shen et al. [66]; Alberini and Bigano [68]; Charlier [69]; and Dubois and Allacker [70]).

2.5. Social and Economic Aspects and Energy Efficiency

Trotta [25] indicated that social and economic factors influence building energy efficiency. Regarding social and economic factors, we discuss income, the Gini coefficient, education, credit, age group, and gender. However, the impact of social and economic aspects on EPCs has not been explored in the literature. Therefore, we opted to use literature closest to this topic issue.

For example, Lakić et al. [23] studied the most important attributes when buying a highly energy-efficient property and investing in more efficient heating controls in Slovenia. According to the authors, energy efficiency is crucial for Slovenians when purchasing properties. It is the second most important factor after property price. Individuals with higher education place more value on future costs and are more willing to invest in energy efficiency due to its increased benefits. Additionally, several studies, such as Gómez-Román et al. [24], Mills and Schleich [37], and Morton et al. (2018) [71], have linked higher education with behaviors related to energy efficiency.

In a study by Gamtessa [72] in Canada, the author examined the residential factors influencing energy efficiency retrofit behavior between October 1998 and September 2005. The study found that higher income levels and a greater proportion of elderly household members are positively associated with energy efficiency retrofit investments. Meanwhile, several other authors, such as Hamilton et al. [73], Hamilton et al. [74] and Tovar [75], have also linked higher income levels with increased energy efficiency. However, Koengkan et al. [76] and Fuinhas et al. [77] have identified that the impact of income on the energy efficiency of housing varies. In the highest-efficiency housing categories (A+, A, and B), income has a negative and significant impact, whereas in the lowest-efficiency categories (C, D, and E), it has a positive and significant impact. Moreover, the impact of income on (B)-level housing is the most significant.

Galvin [78] explored the link between Gini and energy poverty, which is related to low energy consumption efficiency in buildings or houses. The Gini index indicates the discrepancy between people's income levels in a particular country, region, or municipality [78]. The author found that low income is one of the causes of energy poverty in European countries. Moreover, other authors who studied the same link found the same result [79,80].

One economic aspect that may encourage household energy efficiency is credit availability for consumers. Trotta et al. [8] noted that soft loans are frequently used to promote energy efficiency improvements by reducing the upfront costs that households face. These loans may help to increase the adoption of energy-efficient upgrades by making them more affordable and accessible to homeowners. Ameli and Brandt [81] complemented this by stating that in Organization for Economic Co-operation and Development (OECD) countries, low-income families without direct subsidies, tax credits, or rebates opt to use credit to access clean energy technologies with low consumption. Berkouwer and Dean [82] used a randomized controlled trial (RCT) to show that providing access to credit reduces the energy efficiency gap for adopting energy-efficient cookstoves in Kenya.

2.6. Characteristics of Proprieties and Energy Efficiency

McCord et al. [26] argued that properties' characteristics determine specific energy efficiency levels. This view is also shared by Mudgal et al. [7], who suggested that different energy efficiency levels depend on the country, region, or physical attributes. Additionally, Cerin et al. [57] suggested that the energy performance relationship varies according to the type of housing.

When referring to the characteristics of houses or buildings, we typically mean size, property type, age, temperature, and location [25,83]. However, the impact of these characteristics on EPCs has not been explored in the literature. For this reason, we chose to use the literature closest to this topic issue.

For instance, McCord et al. [26] examined the relationship between EPCs and sales prices in Belfast, UK. The authors found that larger properties have less energy efficiency, while smaller properties are associated with more energy efficiency. The property type can also affect energy efficiency, with apartments and terraces showing a positive correlation. In terms of property age, the authors found that older properties have a greater negative effect on energy efficiency, and this effect diminishes as the age classification becomes new.

Trotta [25] investigated the determinants of energy-efficient retrofit investments in the English residential sector. The author found that British households living in houses built before 1990 and living there for more than a year are more likely to invest in energy-efficient retrofit measures. Nair et al. [39] examined the impact of property characteristics, such as building age and thermal comfort, on energy-efficient retrofit investments in Sweden. The authors found that the likelihood of investing in new building envelope components and other energy efficiency measures increases with thermal discomfort and the age of the house. In a study by Gamtessa [72], the relationship between household characteristics and energy-efficient retrofit measures was investigated. The findings indicated that building obsolescence was positively associated with retrofit investments, suggesting that older buildings were more likely to undergo energy-efficient upgrades. Conversely, larger floor area, larger household size, and living in attached/row, mobile, or multi-floor homes were negatively associated with retrofit investments, indicating that these factors may be barriers to retrofit adoption.

3. Data and Methods

This section presents the variables and the methods used to assess the causal conditions leading to buildings' high or low energy consumption performance across Portuguese municipalities.

3.1. Data

Municipalities are political-administrative divisions of the Portuguese territory. Portugal has 308 municipalities, with populations ranging from a few thousand to more than half a million and areas ranging from 7.94 to 1720.6 km^2 (see Figure 7 below).

Indeed, studying energy performance adoption in municipalities is particularly relevant given the global imperative to transition towards a low-carbon, sustainable energy future. Municipalities are key actors in this transition, as they are responsible for a significant proportion of energy consumption and greenhouse gas emissions. By identifying the determinants of high or low energy consumption performance adoption in municipalities, researchers can contribute to developing more effective policies and programs to reduce energy consumption, promote renewable energy, and mitigate climate change. Table 2 describes the variables used in this empirical investigation.

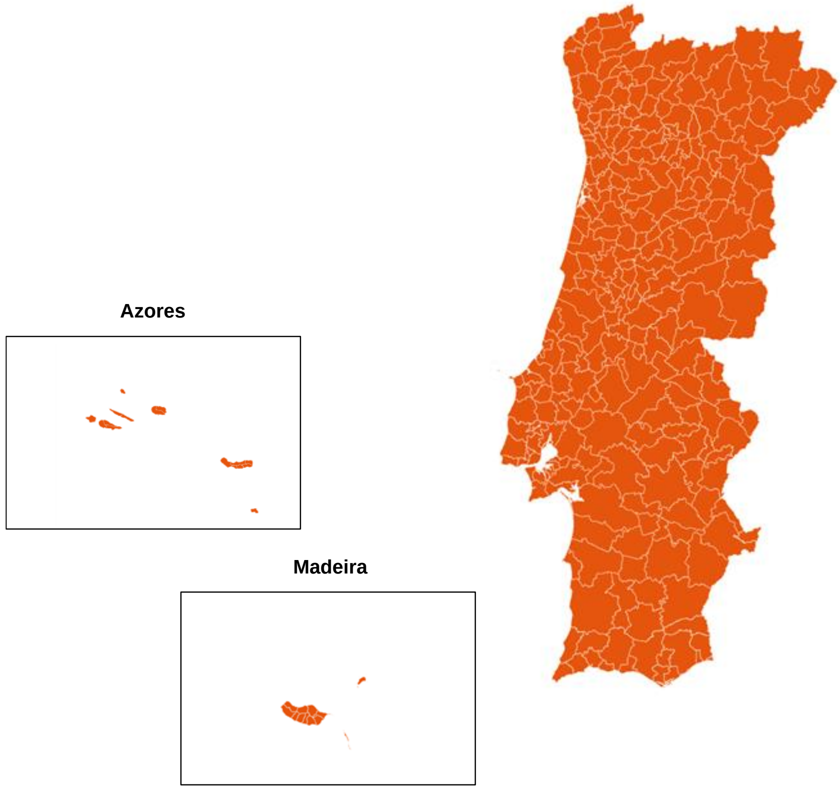

Figure 7. Portuguese municipalities. The authors created this map.

Table 2. Description of the variables.

Variables	Description	Source
High energy performance certificates (EPC-H)	Fraction of the cumulative certificates with high performance in buildings (classes A+, A, and B) on total cumulative energy certificates (%).	*Sistema de Certificação Energética dos Edifícios* [10]
Low energy performance certificates (EPC-L)	Fraction of the cumulative certificates with low performance in buildings (classes D, E, and F) on total cumulative energy certificates (%).	*Sistema de Certificação Energética dos Edifícios* [10]
Fiscal/Financial incentives policies (FIP)	Fiscal/financial incentive policies for energy efficiency for the residential sector. This variable includes grants and subsidies, and tax reliefs. This variable was built in accumulated form, where each policy type that was implemented is represented by (1) accumulated over other policies throughout its useful life (In force) or end (e.g., 1, 1, 2, 2, 2, 3,3).	International Energy Agency [84]
Gross domestic product (GDP)	Gross domestic product per capita at 2016 constant prices (thousand Euros).	*Instituto Nacional de Estatística* [85]
Higher education (HE)	Students currently enrolled in higher education as a fraction of the municipality population (%).	*Direção-Geral de Estatísticas da Educação e Ciência* [86]
Gini coefficient (Gini)	Gini coefficient of gross declared income deducted from personal income tax assessed per tax household.	*Instituto Nacional de Estatística* [85]
Completed dwellings (CD)	Completed dwellings in new construction for family dwelling by municipality per 10,000 inhabitants.	*Instituto Nacional de Estatística* [85]
Completed reconstructions (CR)	Completed reconstructions for family dwellings by municipality per 10,000 inhabitants.	*Instituto Nacional de Estatística* [85]

Notes: This table was created by the authors.

To measure the energy performance of buildings, which is the dependent variable in our model, we retrieved the cumulative number of energy certificates for each class from the Portuguese municipalities using the Sistema de Certificação Energética dos Edifícios (SCE) [10]. In Portugal, there are eight energy classes, ranging from A+ for the most efficient to F for the least efficient. A residential property under A+ has a primary energy demand that does not exceed 25% of the reference consumption, while F classifies a property whose energy consumption is more than two and a half times the reference level. We used these data to define our study variables: (i) high energy performance certificates (EPC-H), which represent the fraction of the three highest classes in the total certificates, and (ii) low energy consumption performance certificates (EPC-L), which represent the portion of the three least efficient classes in the total certificates. We excluded from the analysis the class C certificates as they are less relevant because they represent the average energy performance, and we are interested in assessing the drivers of high and low performance. We chose this normalization to account for the different dimensions of the Portuguese municipalities. Some authors have used this variable as a proxy for energy efficiency performance, such as Koengkan et al. [76], Fuinhas et al. [77], and Koengkan et al. [87].

The use of Fiscal/Financial incentives policies, Gross domestic product (GDP), Higher education (HE), Gini coefficient (Gini), Completed dwellings (CD), and Completed reconstructions (CR) as independent variables to explain energy efficiency performance in houses can be grounded in various economic, social, and environmental theories. In contrast, there may not be specific literature that directly justifies using these variables or relevant studies closely related to this topic. Therefore, this investigation draws on existing literature to support the selection of these variables and their theoretical justification.

For example, we used the variable Fiscal/Financial incentives policies (FIP). This variable was retrieved from the International Energy Agency [84] and is only available nationally. The behavioral economics theory can explain this variable's use in our econometric model. This theory suggests that people are more likely to undertake energy efficiency measures if they are financially incentivized. Financial incentives can help overcome the initial investment costs associated with energy efficiency improvements, making them more attractive to homeowners. Several studies support using this variable to explain the energy efficiency in houses. For example, Trotta et al. [8], Noailly [9], Sarker et al. [21], Filippini et al. [22], Broin et al. [32], He and Chen [60], Neveu and Sherlock [64], Ameer and Krarti [65], Chen and Hong [67], and Sathre and Gustavsson [88]. All authors indicated that the fiscal/financial incentive policies encourage families to install solar panels, improve the thermal insulation of their homes, and replace domestic apparel with others that consume less energy.

The variable Gross Domestic Product (GDP) is used to understand the relationship between economic growth and house energy efficiency. Although GDP data are not available at the municipality level in Portugal, it can be estimated using the per capita GDP of the 25 NUTS III territorial units. Therefore, we used each municipality's NUTS III unit's per capita GDP as a proxy for their per capita GDP. This variable is valid because economic growth theory suggests that increasing energy efficiency is crucial for sustainable economic development. Higher GDP levels tend to be associated with greater investments in energy efficiency in homes. Several studies support the use of per capita GDP as a variable to explain energy efficiency in houses, including Gamtessa [72], Hamilton et al. [73], Hamilton et al. [74], Tovar [75], Koengkan et al. [76], and Fuinhas et al. [77]. These authors have found that higher income levels and a higher proportion of elderly household members are positively associated with energy efficiency retrofit investments. By using per capita GDP as a proxy variable, we can examine the relationship between economic growth and energy efficiency at the municipal level in Portugal.

The variable higher education (HE) was retrieved from the Direção-Geral de Estatísticas da Educação e Ciência [86]. The use of higher education can be explained by the theory of human capital, which suggests that education and knowledge are important factors that influence energy-efficient behavior. People with higher levels of education are more likely to be aware of the benefits of energy efficiency and take steps to improve it. Several studies support the use of higher education as a variable to explain energy efficiency in houses, including Lakić et al. [23], Gómez-Román et al. [24], Mills and Schleich [37], and Morton et al. [71]. These authors indicated that higher levels of education are associated with greater awareness of the benefits of energy efficiency and a greater willingness to invest in energy-efficient measures.

The Gini coefficient (Gini) variable was obtained from the Instituto Nacional de Estatística [85]. The use of the Gini coefficient can be explained by the theory of income inequality, which suggests that income inequality can result in unequal access to energy-efficient housing. Wealthier households may have more resources to invest in energy-efficient technologies and materials. Several studies have supported the use of the Gini coefficient as a variable to explain energy efficiency in homes, such as Galvin [78], Bouzarovski and Simcock [79], Sovacool [80], and Gough et al. [89]. These authors indicated that income inequality could lead to disparities in access to energy-efficient homes.

The variables Completed dwellings (CD) and Completed reconstructions (CR) were obtained from the Instituto Nacional de Estatística [85]. The housing supply and demand theory can explain the use of completed dwellings and reconstructions. This theory suggests that housing stock availability and quality can influence the adoption of energy efficiency measures.

Moreover, new buildings often have a higher energy performance than existing ones, as they are subject to stricter regulations, and builders want to appeal to high-income and sophisticated clients. Reconstructions may also benefit from modern techniques that improve energy efficiency. Some studies have supported the use of the completed dwellings and completed reconstructions as variables to explain energy efficiency in homes, such as Trotta [25], Nair et al. [39], Gamtessa [72], and Attia et al. [90].

The empirical investigation was conducted for the period 2015 to 2019, deemed the most suitable period. This period was chosen because data on the energy efficiency certificate ratings that make up the EPC_H and EPC_L variables were available starting in 2015. Additionally, all municipalities had data available until 2019 for some other variables, such as HE, CD, and CR, making it the logical endpoint for the study.

Table 3 below displays the descriptive statistics for all the variables. After removing cases with missing data, we retain 1316 observations. On average, the share of low-energy consumption certificates (54.16) is much higher than that of high-energy ones (24.48). Their range is very large: from 0 to 66.79 for high energy certificates and 17.24 to 94.90 for low energy consumption certificates. For most municipalities, the share of high-energy certificates is between 10% and 40%, while the majority of low-energy consumption certificates are concentrated in the 30% to 70% range (Figure 8). The number of policies varies between four and six. The per capita gross domestic product shows an average of 16,839 €, with a mild dispersion. On the contrary, the proportion of the population enrolled in higher education varies widely across the municipalities. The same pattern is observed for completed dwellings and reconstructions, suggesting that the dynamics of the construction sector differ greatly between the municipalities.

Figure 9 shows the boxplots for all the variables. Higher Education, the Gini coefficient, and mostly completed dwellings and completed reconstructions have many outliers. However, unlike traditional regression methods, fuzzy set Qualitative Comparative Analysis is robust to this data feature.

Table 3. Descriptive Statistics.

Variables	Descriptive Statistics				
	Obs.	Mean	Std. Dev.	Min	Max
EPC-H	1316	24.48	12.84	0	66.79
EPC-L	1316	54.16	14.23	17.24	94.90
FIP	1316	5.18617	0.75058	4	6
GDP	1316	16.83912	3.55367	10.76508	26.89069
HE	1316	2.79	1.22	0.47	18.13
Gini	1316	42.49438	2.77818	35.9	55.1
CD	1316	11.62	14.74	0	217.76
CR	1316	0.83	2.30	0	30.00

Notes: "Obs." Represents the number of observations, "Std. Dev." The standard deviation, "Min" and "Max" are the minimum and maximum, respectively.

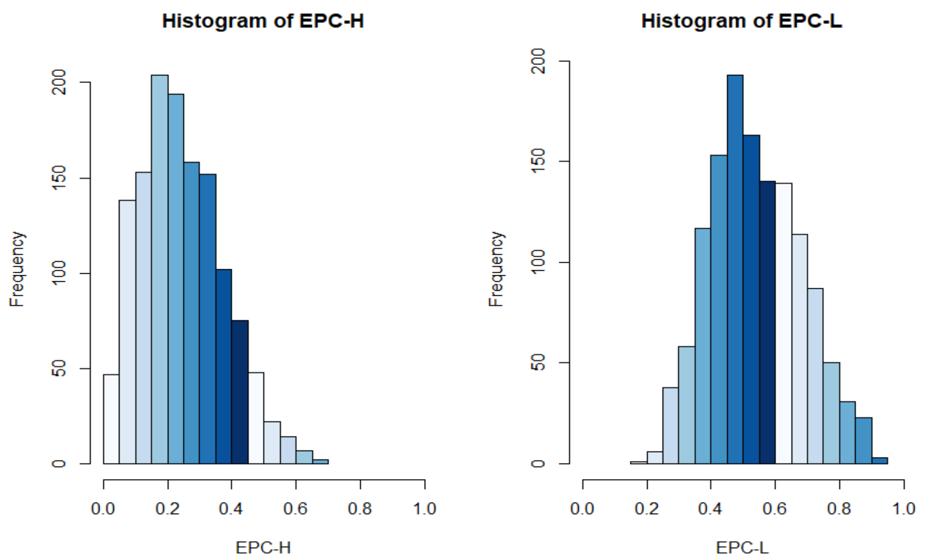

Figure 8. Histogram for high energy performance certificates (EPC-H) and low energy consumption performance certificates (EPC-L).

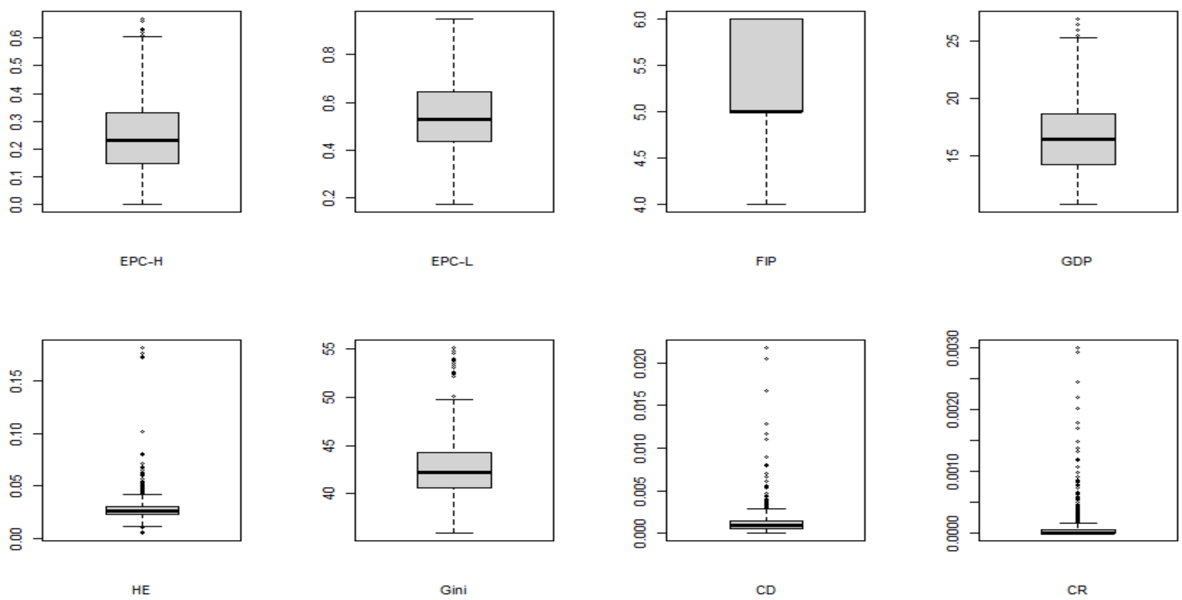

Figure 9. Boxplot for the variables EPC-H, EPC-L, FIP, GDP, HE, Gini, CD, and CR.

Table 4 presents the correlation coefficients between the variables. Most values are statistically significant. High energy performance certificates positively correlate with FIP, HE, CD, and CR, while their correlation with EPC_L, GDP, and the Gini coefficient is negative. Low energy consumption performance certificates are negatively correlated with all the variables.

Table 4. Correlation coefficients.

Variable	EPC-H	EPC-L	FIP	GDP	HE	Gini	CD	CR
EPC-H	1 ***	−0.749 ***	0.319 ***	−0.095 ***	0.096 ***	−0.062 **	0.401 ***	0.234 ***
EPC-L	−0.749 ***	1 ***	−0.087 ***	−0.057 **	−0.195 ***	−0.293 ***	−0.357 ***	−0.168 ***
FIP	0.319 ***	−0.087 ***	1 ***	0.295 ***	0.045 ***	−0.163 ***	0.165 ***	0.025
GDP	−0.095 ***	−0.057 **	0.295 ***	1 ***	0.030	0.248 ***	0.020	−0.130 ***
HE	0.096 ***	−0.195 ***	0.045 ***	0.030	1 ***	0.269 ***	0.179 ***	−0.046 *
Gini	−0.062 **	−0.293 ***	−0.163 ***	0.248 ***	0.269 ***	1 ***	0.009	−0.033
CD	0.401 ***	−0.357 ***	0.165 ***	0.020	0.179 ***	0.009	1 ***	0.498 ***
CR	0.234 ***	−0.168 ***	0.025	−0.130 ***	−0.046 *	−0.033	0.498 ***	1 ***

Notes: "***", "**", and "*" represent statistical significance at the 1%, 5%, and 10% levels, respectively.

3.2. Methods

3.2.1. Fuzzy Set Qualitative Comparative Analysis

In this research, we use fuzzy set Qualitative Comparative Analysis (fsQCA) to find combinations of causal conditions sufficient for high or low energy consumption efficiency performance. This method, developed by Ragin [91], combines fuzzy set theory [92] with Boolean algebra and is well-equipped to deal with the complexity inherent in the real world. The FsQCA focuses on analyzing cases while preserving their complexity, unlike regression methods that strip the attributes from observed cases and attempt to find meaningful relationships between variables. This difference confers several advantages to fsQCA over regression methods. First, fsQCA considers the conjunction of conditions. That is, it allows the influence of a given condition to depend on the values of the remaining conditions. Regression methods, which rely on "net effects" reasoning, exclude this possibility [93,94]. Second, fsQCA can find several different combinations of conditions that lead to the desired outcome (equifinality). Finally, it contemplates the possibility of asymmetric effects of given attributes on different causal recipes. For example, a given attribute that is positively related in a recipe leading to an outcome may be negatively related or unrelated in a different causal combination leading to the same outcome [95].

Another important difference between regression methods and fsQCA is how they use the data. While the former uses the data in their raw form, the latter requires calibrated data in the interval from zero to one, indicating the degree of membership in a given set. In this research, we used the direct calibration method and define the 5%, 50%, and 95% quantiles as thresholds for full exclusion, crossover, and full inclusion in the set.

The second step of this method requires the researcher to construct the truth table. This table displays all possible combinations of causal conditions, the frequency of cases associated with each, and their consistency with the outcome. A real-world feature that affects fsQCA is the problem of limited diversity: some combinations of causal conditions are never observed. Therefore, we need to define a frequency threshold for the combinations that will later be used in the Quine–McCluskey algorithm. Schneider and Wagemann [96] argued that the researcher should choose a frequency threshold that includes at least 75% of the cases, and this threshold should grow with the sample size. Following their advice, we choose a frequency threshold of 6 cases.

Regarding the consistency threshold, we chose the value 80%, which is higher than the minimum acceptable limit suggested by Rihoux and Ragin [97]. Next, we used the Quine–McCluskey algorithm to find complex and parsimonious solutions. The parsimonious solutions include all the remainders (causal combinations with no observed cases) in the minimization process, while complex solutions include none [94].

Finally, we must assess the quality of our causal recipes by measuring their consistencies and coverages. Consistency shows the degree to which a causal combination agrees with the result, while coverage measures the portion of instances of the outcome that respects the causal recipe and indicates its empirical relevance [94]. In our panel data framework, we measured the pooled consistency of a sufficient causal recipe by the degree of inclusion of the set representing the causal combination in the outcome set [94,98].

$$Pooled\ consistency = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T} min(X_{i,t}, Y_{i,t})}{\sum_{i=1}^{N}\sum_{t=1}^{T} X_{i,t}}, \quad (1)$$

where $X_{i,t}$, and $Y_{i,t}$ represent the degree of membership of the case in the causal recipe and the outcome, respectively, while T, and N are the number of years and municipalities. Pooled coverage is characterized by the degree of inclusion of the result in the causal recipe.

$$Pooled\ coverage = \frac{\sum_{i=1}^{N}\sum_{t=1}^{T} min(X_{i,t}, Y_{i,t})}{\sum_{i=1}^{N}\sum_{t=1}^{T} Y_{i,t}}, \quad (2)$$

to detect panel effects, Garcia-Castro and Ariño [98] proposed a cross-section (between) and across-time (within) measures for consistency and coverage. The between consistency is defined as:

$$Between\ consistency = \frac{\sum_{i=1}^{N} min(X_{i,t}, Y_{i,t})}{\sum_{i=1}^{N} X_{i,t}}, \quad (3)$$

for each t = 1, . . . , T. Between coverage is defined similarly-

$$Between\ coverage = \frac{\sum_{i=1}^{N} min(X_{i,t}, Y_{i,t})}{\sum_{i=1}^{N} Y_{i,t}}, \quad (4)$$

for each t = 1, . . . , T. The within consistency and the coverage may be defined analogously. However, we do not use these measures in our study because the time dimension of our panel is very short.

Garcia-Castro and Ariño [98] argued that sizable differences between consistencies across the years may signal unaccounted time effects. To assess the significance of these differences, these authors propose the following measure adjusted distance measure.

$$Adjusted\ distance = \frac{Distance}{\sqrt{\frac{T}{T^2+3T+2}}}, \quad (5)$$

where *Distance* represents the Euclidean distance between the vector containing the cross-section consistencies for all the years and the T-dimensional vector whose elements are all equal to $\frac{1}{T}$.

$$Distance = \sqrt{\sum_{t=1}^{T}\left(\frac{Between\ consistency_t}{\sum_{t=1}^{T} Between\ consistency_t} - \frac{1}{T}\right)}. \quad (6)$$

Garcia-Castro and Ariño [98] claimed that an adjusted distance of fewer than 0.1 signals that there are no significant time effects.

3.2.2. Robustness Check

The standard analysis of fsQCA is prone to finding spurious causal recipes because it relies on analyzing multiple possible combinations from the truth table. Completely random variables added to the model often comprise at least one sufficient condition [99]. Braumoeller [100] proposed a simple permutation test that considers the multiple testing performed in fsQCA to avoid the problem of false positives and adjusts the p-values accordingly. We will use this test to assess the robustness of our results.

4. Results

This section presents the causal recipes leading to a high or low energy consumption efficiency performance. Table 5 shows the combinations of causal conditions sufficient for a high energy consumption efficiency performance, using an 80% consistency threshold and a 6-cases frequency threshold. We performed a sensitivity analysis by considering different consistency (90%) and frequency (5 and 7 cases) thresholds, and the results remained broadly unchanged.

Table 5. Configurations for high energy consumption efficiency.

Configuration → **↓ Variable**	**1**	**2**	**3**	**4**	**5**
FIP	●	●	⊗	●	●
GDP	⊗		⊗	⊗	●
HE	●	●			
Gini		⊗	●	⊗	●
CD	●	●	●	●	●
CR			●	●	●
Consistency	0.907	0.910	0.945	0.941	0.973
Consistency 19	0.945	0.922	1.000	0.957	0.998
Consistency 18	0.929	0.923	0.997	0.936	0.952
Consistency 17	0.907	0.914	0.985	0.960	0.984
Consistency 16	0.826	0.847	0.937	0.895	0.952
Consistency 15	0.985	0.984	0.892	0.984	0.985
Adj. Distance	0.074	0.061	0.056	0.041	0.025
Raw coverage	0.373	0.356	0.181	0.202	0.163
Raw coverage 19	0.373	0.422	0.071	0.204	0.167
Raw coverage 18	0.410	0.398	0.081	0.210	0.171
Raw coverage 17	0.420	0.376	0.216	0.204	0.174
Raw coverage 16	0.488	0.393	0.286	0.252	0.200
Raw coverage 15	0.126	0.122	0.359	0.126	0.125
Overall solution consistency			0.895		
Overall solution coverage			0.501		

Notes: We used the QCA R package to build this table. Consistency P represents the pooled consistency, while Consistency 19, Consistency 18, Consistency 17, Consistency 16, and Consistency 15 are the consistency scores for 2019, 2018, 2017, 2016, and 2015, respectively. The notation for Raw coverage is analogous. Adj. Distance is the adjusted distance between the yearly consistencies. "●" represents the presence of a core condition, "●" the presence of a peripheral condition, and a blank space for the "do not care" condition. "⊗" represents the negation of a core condition, "⊗" the negation of a peripheral condition.

We adopted the notation used by Fiss [93] and represent by "●" the presence of a core condition, "●" the presence of a peripheral condition, and by a blank space the "do not care" condition. The first combination, which features a large number of fiscal and financial incentive policies, a highly educated population, and a large number of completed dwellings, coupled with low GDP, shows pooled consistency and coverage scores of 0.907 and 0.373, respectively. The second causal recipe differs from the first one in only one attribute: a low GDP is replaced by a low inequality, represented by the Gini coefficient. This combination presents a slightly higher pooled consistency (0.910) but a lower coverage (0.356). The third configuration, which includes high inequality, completed dwellings, and completed reconstructions, coupled with a low GDP and the number of policies, exhibits consistency and coverage scores of 0.945 and 0.181, respectively. Finally, the last two configurations only differ in two attributes. Both require many fiscal and financial policies, completed dwellings, and completed reconstructions. However, the fifth one calls for a high GDP and inequality, and the fourth requires their absence. As a result, consistency is slightly higher for the last recipe (0.973 vs. 0.941), while the reverse relation holds for coverage (0.163 vs. 0.202). The overall solution's pooled consistency and coverage scores are 0.895 and 0.501, respectively.

The cross-sectional analysis of consistencies shows slight differences between the scores. The adjusted distance between the yearly consistencies never exceeds 0.1, which suggests that time effects are not a concern.

Table 6 displays the causal recipes leading to low energy consumption efficiency performance. The first configuration requires a low education level and Gini coefficient, few completed dwellings, and reconstructions. This solution's pooled consistency and coverage scores are 0.885 and 0.486, respectively. The last two configurations share several attributes: a low number of fiscal and financial policies coupled with low inequality, few completed dwellings, and a high GDP. However, while the second requires a low educational level, the last calls for a few completed reconstructions. Their pooled consistency scores are similar (0.948 for the second one and 0.941 for the last one), as are their pooled coverages (0.260 for the second one and 0.266 for the last one).

Table 6. Configurations for low energy consumption efficiency performance.

Configuration → **↓ Variable**	**1**	**2**	**3**
FIP		⊗	⊗
GDP		•	•
HE	⊗	⊗	
Gini	⊗	⊗	⊗
CD	⊗	⊗	⊗
CR	⊗		⊗
Consistency P	0.885	0.948	0.941
Consistency 19	0.853	0.967	0.966
Consistency 18	0.866	0.976	0.976
Consistency 17	0.908	0.939	0.933
Consistency 16	0.931	0.975	0.972
Consistency 15	0.854	0.905	0.889
Adj Distance	0.046	0.037	0.045
Raw coverage P	0.486	0.260	0.266
Raw coverage 19	0.513	0.111	0.110
Raw coverage 18	0.480	0.101	0.100
Raw coverage 17	0.509	0.393	0.413
Raw coverage 16	0.430	0.309	0.322
Raw coverage 15	0.520	0.368	0.363
Overall solution consistency		0.884	
Overall solution coverage		0.516	

Notes: We used the QCA R package to build this table. Consistency P represents the pooled consistency, while Consistency 19, Consistency 18, Consistency 17, Consistency 16, and Consistency 15 are the consistency scores for 2019, 2018, 2017, 2016, and 2015, respectively. The notation for Raw coverage is analogous. Adj. Distance is the adjusted distance between the yearly consistencies. "•" represents a core condition and a blank space in the "do not care" condition. "⊗" represents the negation of a core condition, "⊗" the negation of a peripheral condition.

The examination of the yearly consistency scores reveals, once again, that their differences are minor. Furthermore, the adjusted distance is always below 0.1, thus indicating that there are almost no signs of time effects. In the last part of this section, we present the results of the Braumoeller [100] permutation test for high and low energy consumption efficiency performance. We used 10,000 permutations for each test run.

The hypotheses that the configurations for high environmental performance result from mere chance are strongly rejected in all cases. The adjusted p-values are highly significant (see Table 7 and Figure 10 below), and the permuted consistency distributions are always to the left of the observed consistencies.

Table 7. Consistency for high energy consumption efficiency performance.

Configuration	Observed	Lower Bound	Upper Bound	Adjusted *p*-Value
FIP × ~GDP × CD × HE	0.907	0.759	0.820	0.000
FIP × CD × HE × ~Gini	0.910	0.755	0.821	0.000
~FIP × GDP × CD × Gini × CR	0.945	0.811	0.897	0.000
FIP × ~GDP × CD × ~Gini × CR	0.941	0.793	0.879	0.000
FIP × GDP × CD × Gini × CR	0.973	0.845	0.920	0.000

Note: The Braumoeller [100] permutation test results are based on 10,000 replications.

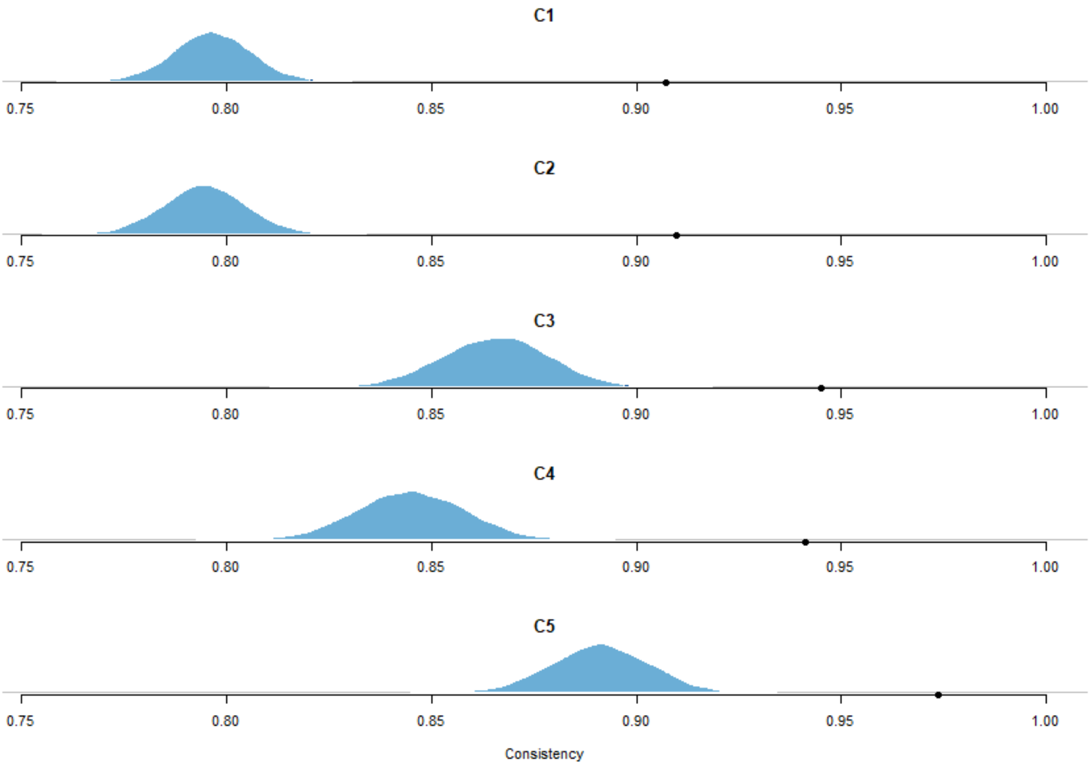

Figure 10. Observed consistencies and consistency distributions based on permutations for high energy consumption efficiency performance. **Notes**: The permutation test is based on 10,000 replications. C1—FIP × ~GDP × CD × HE. C2—FIP × CD × HE × ~Gini. C3—~FIP × GDP × CD × Gini × CR. C4—FIP × ~GDP × CD × ~Gini × CR. C5—FIP × GDP × CD × Gini × CR. The dots represent the observed consistency scores, and the distributions are the permuted ones.

We reached the same conclusion for configurations leading to a low energy consumption efficiency performance. The hypotheses that the causal recipes are spurious are strongly rejected (See Table 8 and Figure 11 below).

Table 8. Consistency for low energy consumption efficiency performance.

Configuration	Observed	Lower Bound	Upper Bound	Adjusted *p*-Value
~CD × ~HE × ~Gini × ~CR	0.885	0.734	0.783	0.000
~FIP × ~CD × GDP × ~HE × ~Gini	0.948	0.799	0.868	0.000
~FIP × ~CD × GDP × ~CR × ~Gini	0.941	0.793	0.861	0.000

Note: The Braumoeller [100] permutation test results are based on 10,000 replications.

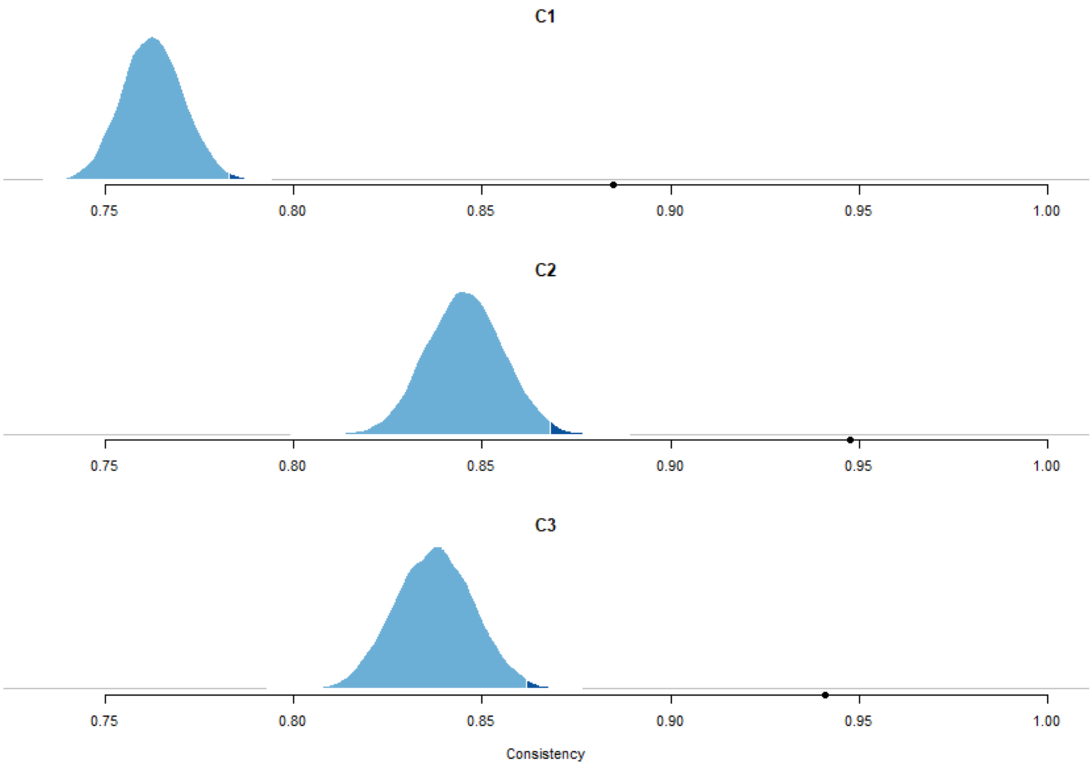

Figure 11. Observed consistencies and consistency distributions based on permutations for low energy consumption efficiency performance. **Notes**: The permutation test is based on 10,000 replications. C1—~CD × ~HE × ~Gini × ~CR. C2—~FIP × ~CD × GDP × ~HE × ~Gini. C3—~FIP × ~CD × GDP × ~CR × ~Gini. The dots represent the observed consistency scores, and the distributions are the permuted ones.

5. Conclusions and Policy Implications

Causal conditions leading to high and low energy consumption efficiency performances of dwellings were researched for Portuguese municipalities, using data disaggregated by the municipality for the period 2015 to 2019, using a panel fuzzy set Qualitative Comparative Analysis. The study used, as the explained variable, the energy performance certificates. We considered high-energy consumption performance certificates (classes A+, A, and B) on total cumulative energy certificates (%). For low energy performance certificates we used the cumulative certificates with low consumption performance (classes D, E, and F) on total cumulative energy certificates (%). The explanatory variables comprise (i) fiscal/financial incentive policies for energy efficiency for the residential sector, (ii) gross domestic product per capita at 2016 constant prices, (iii) the portion of the population of each municipality that is enrolled in higher education (%), (iv) the Gini coefficient of gross declared income deducted from personal income tax assessed per tax household, (v) completed dwellings in new construction for family dwelling by municipality per 10,000 inhabitants, and (vi) completed reconstructions for family dwelling by municipality per 10,000 inhabitants.

The study's results support that several combinations of variables cope with this goal to achieve the energy performance of dwellings. However, the study also reveals that causal conditions of high energy consumption efficiency were not symmetric to low energy consumption efficiency. These results confirm that the energy performance of dwellings (i) is complex, (ii) requires the use of statistical techniques able to handle asymmetrical multiple causal conditions, (iii) the causal conditions of high energy consumption efficiency dwellings are more diversified (five causal conditions) than for low energy consumption efficiency of dwellings (three causal conditions), and (iv) the transitions from low to the high energy consumption performance of dwellings involve the management of variables through time.

Five causal conditions are sufficient for high energy consumption efficiency performance in dwellings. These causal conditions include many fiscal and financial incentive policies, a highly educated population, and many completed dwellings coupled with low GDP. The study also found that a high disparity between completed dwellings and completed reconstructions, coupled with a low GDP and few policies, can lead to high energy consumption efficiency performance. The study also showed slight differences between the yearly consistencies, supporting that time effects are not disturbing. On the other hand, a low education level, Gini coefficient, few completed dwellings, and reconstructions, coupled with few fiscal and financial policies, can be causal conditions leading to low energy consumption efficiency performance of dwellings.

Three causal conditions are sufficient for low energy consumption efficiency performance in dwellings. The configurations involve (i) low education level and Gini coefficient, few completed dwellings and reconstructions, (ii) few fiscal and financial policies, low inequality, few completed dwellings, low educational level, and a high GDP, and (iii) few fiscal and financial policies, low inequality, few completed dwellings, few completed reconstructions, and a high GDP. Furthermore, the yearly consistency scores reveal almost no signs of time effects.

The study innovates by confirming the relevance of variables identified in the literature, but with the nuance of multiple configurations achieving high (or low) energy consumption efficiency performance in dwellings.

The study reveals that the factors causing low energy efficiency in dwellings differ from those responsible for high energy consumption efficiency, highlighting the importance of tailored policies. To that end, the following policy recommendations are suggested: (i) Increase fiscal and financial incentives for energy efficiency in the residential sector. Municipalities should prioritize policies that offer tax breaks, subsidies, and other financial incentives to homeowners who invest in energy-efficient home upgrades. (ii) Enhance the educational level of the population, with an emphasis on environmental and energy literacy. Municipalities should promote educational programs and initiatives to raise awareness among homeowners about the benefits of energy-consumption-efficient homes and provide them with the knowledge and skills to make informed decisions. (iii) Promote the construction and reconstruction of energy-efficient homes. Municipalities should encourage and facilitate new construction and reconstruction of existing buildings to increase the number of energy-efficient homes in their communities. (iv) Address income inequality. Municipalities should prioritize policies that reduce income inequality, as low-income households may not have the financial resources to invest in energy-efficient upgrades. (v) Design targeted policies for low energy consumption efficiency performance. Municipalities should devise policies targeting the causal conditions leading to low energy consumption efficiency performance in dwellings, such as education, fiscal and financial incentives, and completed dwellings and reconstructions. (vi) Address territorial diversity. Municipalities should evaluate which configurations for high or low energy consumption efficiency performance better service their path to achieving efficient dwellings. (vii) Monitor and evaluate policy outcomes over time. Municipalities should track the effectiveness of energy efficiency policies and adjust them to ensure they achieve the desired outcomes.

Overall, the study highlights the need for a multifaceted approach to achieve energy efficiency in dwellings with tailored policies that account for the unique causal conditions in each municipality. By prioritizing policies that enhance education, offer fiscal and financial incentives, and promote energy-efficient constructions and reconstructions, municipalities in Portugal can work towards achieving high energy consumption efficiency performance in dwellings, improving residents' quality of life, and contributing to a more sustainable future.

5.1. Study Limitations

The primary limitation of this research was the restricted number of variables that could be analyzed at the municipality level, which limited the extent of complex analysis that could be performed. Including sociological variables that could capture the influence of household lifestyles and expectations is particularly relevant. Furthermore, this study requires further cross-validation to improve the reliability and confidence of our empirical findings. The current state of the art in the literature is still in its infancy, which restricts the depth of discussion. Additionally, the research would benefit from complementary analysis using other econometric techniques that can assess individual configurations identified by the fsQCA analysis, allowing for a more comprehensive examination of the results. Despite these limitations, this study provides valuable insights into the factors that influence energy efficiency in dwellings, and future research should consider the importance of sociological variables and explore other analytical techniques to enhance our understanding of the topic.

5.2. Further Research

Future research can expand on this study by extending the analysis to municipalities in other countries. This approach could identify more general causal configurations and add new variables to the existing literature. Additionally, future research could employ necessary condition analysis models to identify the essential factors and bottlenecks for energy efficiency performance in dwellings. Another fruitful avenue for future research is to incorporate techniques that can pre-identify municipalities that share common characteristics, reducing the disturbing effect of high levels of heterogeneity. Furthermore, future research could explore using qualitative methods, such as interviews and surveys, to gain a more in-depth understanding of the sociological and cultural factors that influence energy efficiency performance in dwellings. Finally, additional research could investigate the impact of policy interventions on energy efficiency in dwellings, providing insights into effective policy design and implementation. By conducting further research, we can improve our understanding of the factors influencing energy efficiency in dwellings and develop more effective strategies for promoting sustainable and energy-efficient housing.

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Article

Building a Sustainable Future: How Eco-Friendly Homes Are Driving Local Economic Development in Lisbon Metropolitan Area

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Abstract: This article explored the impact of eco-friendly houses on economic development in the Lisbon metropolitan area. The study analyzed data from 18 municipalities between 2014 and 2020 using regression analysis with ordinary least squares (OLS) and fixed effects. The results indicate that national policies promoting residential energy efficiency positively impact economic development. Policies like subsidies, loans, and tax relief encourage homeowners to invest in energy-efficient technologies, boosting household disposable income and contributing to economic growth. The study found that an increase in the number of new constructions positively impacts economic development, leading to job creation and increased demand for construction materials and services. Additionally, growing eco-friendly houses can reduce energy consumption, lowering energy costs for homeowners and businesses and ultimately stimulating economic growth. In contrast, increasing the number of non-eco-friendly houses can have negative economic impacts. A robustness check using the method of moments quantile regression (MM-QR) confirmed the results from OLS with fixed effects, providing additional evidence supporting the robustness of the results.

Keywords: eco-friendly houses; economic development; national policies; energy efficiency; GDP per capita; regression analysis

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1. Introduction

Buildings account for a significant share of urban energy consumption and greenhouse gas (GHG) emissions. In 2021, the building sector accounted for 30% of global final energy consumption and 27% of total energy sector emissions [1]. Buildings are also threatened by anticipated climate effects such as urban heat island effects, flooding, and other extreme weather events [2]. Therefore, in recent years, sustainable buildings have become vital to ensure environmental sustainability. Buildings play an essential role in sustainable development, and energy-efficient or green buildings are a key component of sustainable cities and low-carbon economic growth (e.g., [3–6]).

In the European Union (EU), buildings also account for a significant share of consumption. 40% of energy consumption and 36% of GHG emissions are produced by buildings, mainly resulting from usage, construction, renovation, and demolition. In the EU, the building stock is old and changes relatively slowly. More than 220 million building units, or 85% of the building stock in the EU, were constructed before 2001. As expected, most of the buildings in Europe are not energy efficient, mostly using fossil fuels for heating and cooling and old technologies and inefficient equipment [7]. Thus, the EU developed a legal framework to enhance the energy efficiency of buildings to achieve decarbonized buildings by 2050. The achievement of the EU's climate goals implies that the building sector must reduce GHG emissions by 60% by 2030 and fully decarbonize by 2050. However, 85–95% of the existing structures are expected to still stand by 2050 [8].

Many factors, including energy policies, geography, income level, structural features, and energy infrastructure, affect energy consumption in buildings. Therefore, the residential building sector in the EU is far from homogeneous, as it varies significantly across and within member states (e.g., [9–11]). For instance, in the EU region, Southern European countries have lower residential sector energy consumption [12]. Portugal deserves deeper consideration among Southern European countries because of its unique characteristics (e.g., [13,14]). First, the residential sector's final energy consumption for heating and cooling varies significantly across European countries. However, buildings in Southern European countries, including Portugal, are less resilient to climate change than in Northern European countries [15]. Second, the Portuguese building stock is old. Around 15% of Portuguese structures were constructed before 1945, and over 70% before 1990 [16]. Third, the building stock in Portugal needs renovation. About 34% of buildings in Portugal require structural and energy-related renovations, while over 50% require significant renovations to satisfy current comfort and safety requirements [17]. Finally, accounting for 17% of Portugal's total energy consumption, the building sector is the third most energy-intensive sector [18]. Due to these reasons, focusing on energy efficiency in the Portuguese housing sector is essential for the region's environmental quality and residents' quality of life. It can guide other countries with similar characteristics.

Increasing the energy efficiency of houses and building houses with high energy efficiency, namely eco-friendly houses, comes with significant environmental, health, social, and economic benefits (e.g., [2,8]). Among these, the first benefit is environmental. Building energy-efficient houses can reduce GHG emissions and air pollutants, improve air and waste quality, and slow climate change. Second, energy-efficient eco-friendly houses have positive effects on health. In addition to CO_2 emissions, burning fossil fuels and biomass for heating emits various air pollutants that harm human health. There is a direct relationship between energy poverty, housing conditions and health conditions, such as physical and mental problems, mortality risk, etc. [19]. Third, the social benefits of green buildings mostly refer to the contributions that improve the living standards of occupants. Green buildings can improve the overall quality of life and efficiency of occupants [20]. Therefore, one can say that housing and environmental conditions are important factors for individual human well-being. According to van Praag et al. [21], individual satisfaction or subjective well-being with different domains may be linked to satisfaction with life as a whole. In other words, satisfaction with life as a whole can be considered an aggregate concept, which can be unfolded into its domain components. Satisfaction with life as a whole depends on several factors, such as job satisfaction, financial satisfaction, and health satisfaction. One of these factors is satisfaction with housing and the environment (e.g., [22,23]). Besides, housing conditions are also closely linked to the happiness of cities and individuals. One of the factors that create happiness in cities is housing characteristics and quality.

Housing conditions are an essential factor in determining the ranking of happy cities. Many indexes (i.e., the Global Liveability Index, the Urban Environment Quality Index, Mercer Quality of Living Index) measuring the factors related to the happiness or quality of living level of cities consider housing conditions. For example, the Mercer Quality of Living Index (is based on several criteria, including housing, natural environment, and recreation [24]. Thus, one can say that housing and living conditions are essential factors affecting happiness or quality of living standards and ranking of happy cities. Fourth, the rise in eco-friendly housing has significant economic implications for a country or region (e.g., [25,26]). Building energy-efficient houses may affect local economic growth and development through several channels. First, green buildings will require significant investments in new clean, and energy-efficient technologies, which will increase productivity growth (i.e., economic growth). Second, households will likely spend less of their disposable income on energy. Due to more energy-efficient homes and technology, households will pay cheaper energy bills and can allocate funds to other goods and services. Third, a country will spend less on energy imports by decreasing demand and dependence on fossil fuels. Therefore, the country can reallocate more resources toward other investments. Fourth, green building design and construction offer significant job creation potential. Renovations of buildings are mostly labour-intensive and generate employment and investments frequently rooted in local supply chains (e.g., [2,8]).

In the literature, some authors (e.g., [7,27–34]) have investigated the impact of eco-friendly or green buildings on economic growth and development in different countries. Some studies (e.g., [35–38]) have empirically shown a positive relationship between green buildings and energy efficiency. In addition, a few recent studies (e.g., [11,12,14,15]) have focused on Portugal and examined the relationship between energy-efficient or eco-friendly houses and other factors, such as financial and fiscal incentive policies and energy efficiency regulations. Despite these studies focusing on Portugal, no study has investigated the effect of green buildings on local economic development in Portugal. As mentioned earlier, an increase in eco-friendly homes comes with environmental benefits, but it also has significant economic implications and may be important for the local development of regions.

This investigation elaborates on the following research question: How do eco-friendly or greenhouses/buildings impact economic development in the Lisbon Metropolitan area?

Two hypotheses have been formulated to indicate the potential impacts of eco-friendly or greenhouses/buildings on economic development in the Lisbon Metropolitan area:

Hypothesis 1. *Eco-friendly or greenhouses/buildings positively impact economic development in the Lisbon Metropolitan area. This hypothesis suggests that buildings constructed with eco-friendly materials and technologies may contribute positively to the economic development of the Lisbon Metropolitan area. This could be due to various reasons, such as increased energy efficiency, reduced maintenance costs, and improved air quality, which could ultimately lead to lower operating costs for businesses and stimulate economic growth in the region.*

Hypothesis 2. *Eco-friendly or greenhouses/buildings do not significantly impact economic development in the Lisbon Metropolitan area. This hypothesis proposes that eco-friendly or green buildings may not significantly impact economic development in the Lisbon Metropolitan area. While these buildings may offer environmental benefits, their economic impact may be limited due to higher upfront costs and potentially longer payback periods. Furthermore, other factors such as market demand, location, and availability of financing could be more important drivers of economic development in the region.*

The investigation will analyze the impact of eco-friendly houses on economic growth in 18 municipalities of the Lisbon metropolitan area from 2014 to 2020 to confirm one of these hypotheses. The study will use regression analysis with ordinary least squares (OLS) and the Method of Moments Quantile Regression (MM-QR) with fixed effects. Furthermore, the analysis will consider other factors that could potentially affect local development, including national policies for residential energy efficiency and the number of new family housing constructions and reconstructions. By doing so, the investigation aims to provide a broader perspective and a more comprehensive understanding of the relationship between local economic development and eco-friendly homes.

The literature on energy-efficient buildings and economic development is relatively scarce and innovative. Very few studies have investigated the impact of eco-friendly homes on local economic development. Thus, this paper contributes to the existing literature on three fronts. First, to the authors' best knowledge, this study is the first to investigate eco-friendly houses' impact on economic development in the Lisbon metropolitan area.

Second, this study employs a macroeconomic approach and several econometric techniques to analyze the link between local economic development and eco-friendly houses for a sample of Portuguese municipalities within the Lisbon metropolitan area. Third, this study seeks to build on previous research on Portugal [14] by introducing a new econometric model focused on the municipalities of the Lisbon metropolitan area and analyzing the impact of eco-friendly houses on local economic growth.

This investigation is highly relevant because it provides valuable insights into the mechanisms of local economic development and eco-friendly houses. The study highlights the importance of energy-efficient buildings and emphasizes the need for better strategies and policies to promote sustainable development. The results of the investigation can be helpful for policymakers and governments to formulate more effective green policies and initiatives that can reduce total energy consumption and greenhouse gas emissions while promoting local development in Portugal. Additionally, the study could guide other European countries facing similar challenges related to sustainable development and eco-friendly housing. By providing evidence-based recommendations and insights, this investigation can contribute to developing more sustainable and environmentally responsible policies and practices in the housing and urban development field.

A systematic approach was followed by a set of scientific method steps to achieve high clarity, coherence, and structure in this investigation, as depicted in Figure 1 below.

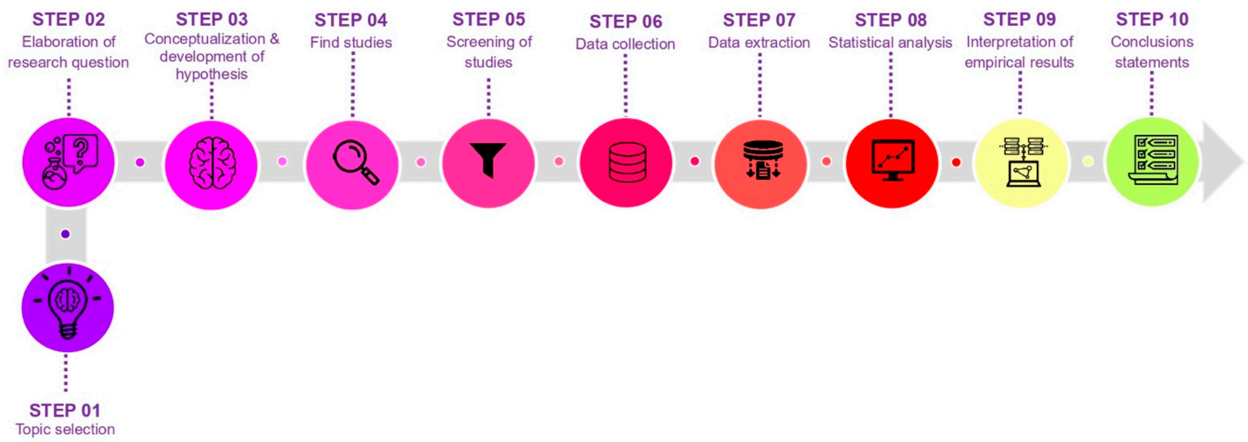


Figure 1. Scientific method steps. This figure was created by the authors.

This paper summarizes the related literature in the next section as a foundation for the subsequent sections. Section 3 presents the research methodology and data, while Section 4 discusses the empirical results. The main findings are comprehensively discussed in Section 5, and valuable policy implications are provided in the concluding Section 6.

2. Literature Review

Eco-friendly buildings offer numerous benefits recognized by various sources (e.g., [1,2,7,8,37,39–42]). These benefits range from direct contributions to balancing the energy trilemma to widespread indirect advantages, including economic, environmental, and societal benefits.

Energy-efficient buildings significantly reduce energy consumption. On average, Energy Star- and Leadership in Energy and Environmental Design (LEED-)certified buildings consume 35% and 25% less energy, respectively [43]. In the EU, building renovations resulted in annual primary energy savings of 8.8% for residential buildings and 17% for non-residential buildings from 2012 to 2016 [44]. Globally, the IEA [45] estimates that energy efficiency improvements can decrease buildings' energy consumption by 25% between 2020 and 2030. As the building sector is a major energy consumer and a significant source of greenhouse gas (GHG) emissions ([1,7]), demand reductions achieved through energy efficiency improvements lead to more sustainable, reliable, resilient, and affordable energy systems.

Green buildings have consistently shown a strong correlation with reductions in CO_2 emissions. The United States (U.S) Department of Energy (DoE) conducted a review of 22 LEED-certified buildings managed by the General Services Administration and discovered a 34% decrease in CO_2 emissions, along with a 25% reduction in energy consumption and an 11% decrease in water consumption [43]. Ferrantelli and Kurnitsk [46] analyzed various building types in Estonia. They found that eco-friendly buildings could reduce CO_2 emissions by at least 26% in educational buildings by 2030, based on a 24,898 Energy Performance Certificates (EPCs) database for Estonian buildings. However, Amiri et al. [47] noted that LEED and Building Research Establishment Environmental Assessment Method (BREEAM) certificates fail to account for embodied emissions. Röck et al. [48] emphasized that energy efficiency measures in buildings might be offset or outweighed by additional emissions from building materials and technical systems. A systematic review of over 650 individual building Life Cycle Assessment (LCA) studies by the authors revealed a "carbon spike" in residential buildings due to the production of building materials and systems, leading to increased embodied GHG emissions. However, office buildings showed a decrease and stabilization of embodied GHG emissions. The importance of adopting a whole lifecycle approach to buildings is increasingly recognized in the literature (e.g., [4,20,48]), and the Level(s) European framework for sustainable buildings, developed by the European Commission, underscores this concept [49]. Considering the entire life cycle of buildings could yield even greater reductions. Karlsson et al. [50] found that GHG emissions in the construction sector supply chain can be reduced by up to 40% with currently available technologies and practices, and even higher reductions of 80% by 2030 and 93% by 2045 are achievable.

Eco-friendly buildings offer various benefits, including mitigating peak loads, congestion, and supply disruptions and reducing the need for expanding energy infrastructure and imports (e.g., [8,41,43]). These energy savings enhance energy security, trade balance, and resource allocation (e.g., [43]). Furthermore, eco-friendly buildings reduce operational and maintenance costs, lowering energy bills and improving structural features (e.g., [39,41,42]). Homeowners can save an average of 15–20% on utility bills and decrease operational costs by up to 37% [51]. This saving contributes to alleviating energy poverty, increasing disposable income, and stimulating economic growth (e.g., [30,32]; [41]). For businesses, eco-friendly buildings result in substantial savings, productivity gains, and improved competitiveness, boosting the economy (e.g., [36,39,41,42]). It is important to note that empirical research on the energy-growth relationship has produced mixed and contradictory results, with varying hypotheses and rebound effects (e.g., [52,53]).

Regarding the impact of energy efficiency improvements on economic growth, the literature suggests positive effects in high-income countries (e.g., [54,55]). A Cambridge Econometrics [56] study analyzed different scenarios for the EU, showing that enhanced energy efficiency leads to the largest positive effect on Gross domestic product (GDP), with increases ranging from just above 0.3% in 2025 to 0.6% in 2030 compared to 2020 baseline levels. The minimum efficiency and REPowerEU Efficiency scenarios also result in higher GDP, ranging from 0.2% to 0.5% by 2030 (e.g., [56,57]). Studies in Portugal have found a positive relationship between energy efficiency and economic growth (e.g., [58,59]). These findings support the idea that energy efficiency is associated with sustainable growth [60].

The literature presents varying perspectives on the magnitude of the rebound effect [61], indicating that energy consumption in buildings is influenced by multiple factors. Consequently, the net savings from energy efficiency improvements differ across countries and regions (e.g., [41,57]). Context-specific policies for rebound mitigation should be implemented to address rebound effects [61,62]. Furthermore, it is essential to consider the multidimensional and long-lasting impact of energy efficiency measures and their direct and indirect benefits (e.g., [56,63,64]).

In addition to mitigating climate change and reducing greenhouse gas emissions, eco-friendly buildings contribute to improved air quality, reduced urban heat island effect, and the prevention of adverse health effects [8]. The built environment significantly impacts human health, with poor indoor conditions leading to various illnesses and diseases (e.g., [41,65]). Green buildings, on the other hand, enhance occupants' health, comfort, and satisfaction, as evidenced by empirical studies ([66,67]). Improved indoor environments in housing and workplaces have been linked to positive outcomes such as respiratory health, mental well-being, school attendance, and increased productivity (e.g., [41]).

Besides upholding human rights, substantial savings and productivity gains can be achieved through energy efficiency improvements. Fisk's [68] study estimated potential annual savings and productivity gains in the U.S., including improvements in worker performance, reduced sick-building syndrome symptoms, and decreased respiratory diseases and allergies. The Eurofund [31] projected that addressing severe housing inadequacies in the EU could lead to significant societal medical cost savings. For every €3 (Euros) invested in reducing housing hazards, approximately €2 (Euros) could be saved in medical costs within a year.

Energy efficiency improvements in buildings offer numerous benefits to businesses, citizens, and governments. Green buildings reduce insurance, environmental, and regulatory compliance costs and mitigate sustainability and reputational risks, including the risk of devalued assets [51]. They also command higher sales prices and rental rates, as demonstrated by various authors (e.g., [51,69,70]). The IFC [51] reports that green commercial buildings achieve sale premiums of up to 31%, faster sale times, higher occupancy rates (up to 23%), and increased rental income (up to 8%). Regarding eco-friendly dwellings, scholars have no consensus on the effect of energy performance certificates (EPCs) on transaction prices and rents. However, Koengkan and Fuinhas [71] found that performance certificates associated with green dwellings increase the value per m^2 of dwelling sales in Portugal through innovative econometric and microeconomic approaches.

The green building sector has significant job creation potential. The European Commission [49] highlights that energy efficiency in buildings generates the most jobs per million euros invested. Various studies support this claim. UNEP [40] found that energy efficiency investments in new buildings and retrofits could create 9 to 30 jobs per year in manufacturing and construction for every United States dollar (USD) 1 million invested. The IEA [72] estimates that building and appliance efficiency improvements could create 10–15 jobs for every USD 1 million invested. Garrett-Peltier [73] estimates 7.49 full-time-equivalent (FTE) jobs in renewables and 7.79 FTE jobs in energy efficiency for every USD 1 million spent, with a portion of those jobs being indirect. Pollin et al. [74] estimate that building retrofits in the U.S. could create 16.7 jobs for every USD 1 million invested, including direct, indirect, and induced jobs.

The demand for energy efficiency drives high-value-added services and technological innovation, leading to investments, economic growth, and high-income jobs. Bertoldi and Rezessy [75] suggest that the market for energy efficiency services in Western Europe has substantial growth potential. Noailly [76] found that policy instruments aimed at improving building efficiency led to increased technology patenting. Green buildings may also have a positive impact on tourism (e.g., [2,77]).

The construction sector offers the greatest potential for job creation. The European Commission [49] estimates that a renovation wave could result in an additional 160,000 green jobs in the EU's construction industry. Cambridge Econometrics [56] projects that the EU construction sector, particularly involved in retrofitting and insulation projects, could experience employment growth between 1.1% (in the minimum efficiency scenario) and 1.4% (in the enhanced efficiency scenario) by 2030.

The construction industry plays a vital role in employment and economic growth, being both labour-intensive and having a multiplier effect on the local economy [78]. The National Association of Home Builders [79] studied the local impacts of various building scenarios and found that significant income, jobs, and revenue for local governments could be generated. In Portugal, the construction sector experienced positive growth in gross value added (GVA) and employment, contributing significantly to the country's GDP and employment rate (e.g., [80–82]).

Eco-friendly buildings offer several benefits, including increased tax revenues and reduced public spending on healthcare and unemployment [83]. However, few studies have comprehensively assessed the aggregated benefits of green buildings. Cambridge Econometrics [84] estimated the economic and fiscal impacts of energy-efficient homes in the United Kingdom (UK), highlighting significant returns on government investment, improved GDP, increased tax revenues, job creation, energy bill savings, CO_2 reductions, and reduced natural gas imports. Copenhagen Economics [56] found that energy-saving renovations in the EU building stock would provide permanent annual societal benefits, including lower energy bills, reduced air pollution, and potential health benefits.

Additional studies have investigated the impact of eco-friendly or green buildings on economic growth and development in different countries [28]. These studies contribute to the growing body of evidence supporting the positive economic outcomes associated with eco-friendly building practices.

Few studies have examined the impact of green buildings on local economic development. Allen and Potiowsky [85] analyzed the green building cluster in Portland and estimated the wages associated with the sector. Choi et al. [86] evaluated the economic and environmental impacts of building efficiency investments in Hamilton County, Ohio, finding significant local economic impacts and job creation. However, these studies lacked broader quantitative assessments of the sector's economic contribution. To our knowledge, no study has investigated the effect of green buildings on local economic development in Portugal. Therefore, this paper aims to contribute to the existing literature by examining the impact of eco-friendly homes on economic development in the Lisbon metropolitan area.

Green construction and renovation investments are increasing globally, with building efficiency investments reaching USD 237 billion in 2021, representing a 16% annual increase from 2020 [87]. The construction of new green buildings presents a substantial investment opportunity of $24.7 trillion by 2030, particularly in residential construction [51]. The retrofit market is also projected to grow significantly, reaching $210.37 billion in 2028 [88].

Despite these investments, the building sector is not on track to meet the decarbonization targets outlined in the Paris Agreement. The UNEP/Global Alliance for Buildings and Construction index for buildings decarbonization was far below the target in 2021 [40], and the annual energy efficiency renovation rates must increase globally to meet the goals [87]. The European Commission acknowledges the need for higher renovation rates and additional investments to meet targets [49], highlighting an investment gap in the building renovation sector.

Various authors have identified barriers to energy efficiency investments in buildings, such as high construction costs, lack of alignment of incentives, low awareness of non-energy benefits, and fragmented legal and institutional frameworks. These barriers can be addressed through well-tailored, targeted policies (e.g., [37,41,51]). Effective policy mixes that offer stability, flexibility, and simplicity can promote increased demand for retrofitting and a more responsive supply side [89]. Financial and fiscal incentive policies can also positively impact energy efficiency ratings in residential properties [11].

3. Data and Method

This section will present the data and methods for this investigation. The methodology framework that will be followed in this investigation is illustrated in Figure 2 below.

Hence, Section 3.1 will present the data/variables, while Section 3.2 will provide a detailed description of the methodology.

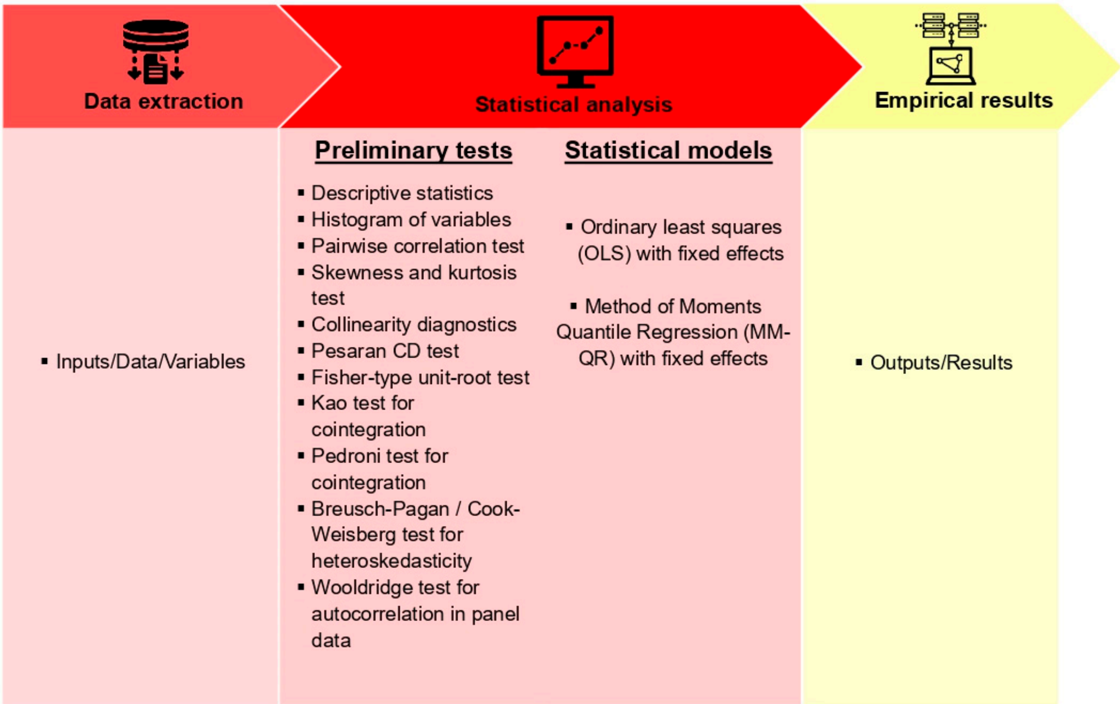


Figure 2. Methodology framework. This figure was created by the authors.

3.1. Data

As mentioned earlier, the initial stage of our empirical investigation involves data collection. Therefore, this subsection presents the data/variables used in our empirical investigation of 18 Portuguese municipalities within the Lisbon Metropolitan Area for 2014 and 2020. The municipalities included in the study are Alcochete, Almada, Amadora, Barreiro, Cascais, Lisbon, Loures, Mafra, Moita, Montijo, Odivelas, Oeiras, Palmela, Seixal, Sesimbra, Setúbal, Sintra, and Vila Franca de Xira (see Figure 3 below).

This group of municipalities was chosen because the Lisbon Metropolitan Area, Portugal's largest urban region, is a diverse area with varying levels of economic development. The adoption of ecological houses, which are energy-efficient and environmentally friendly, has become a crucial topic in urban planning due to the growing interest in sustainable development and reducing environmental impacts.

The Lisbon Metropolitan Area, in central-south Portugal, is categorized as a sub-region and a Nomenclature of territorial Units for Statistics (NUT) II region. Its central hub is the capital city of Lisbon. With a population of 2,871,134 residents, it is the most densely populated region in the country, with 957 inhabitants per km^2. Additionally, it has the largest urban area in Portugal, covering a total area of 3001 km^2, ranking as the fifth largest region in the country. This area is also recognized as the wealthiest region in Portugal, with a per capita GDP of €29,291 (Euros) in 2020 [14].

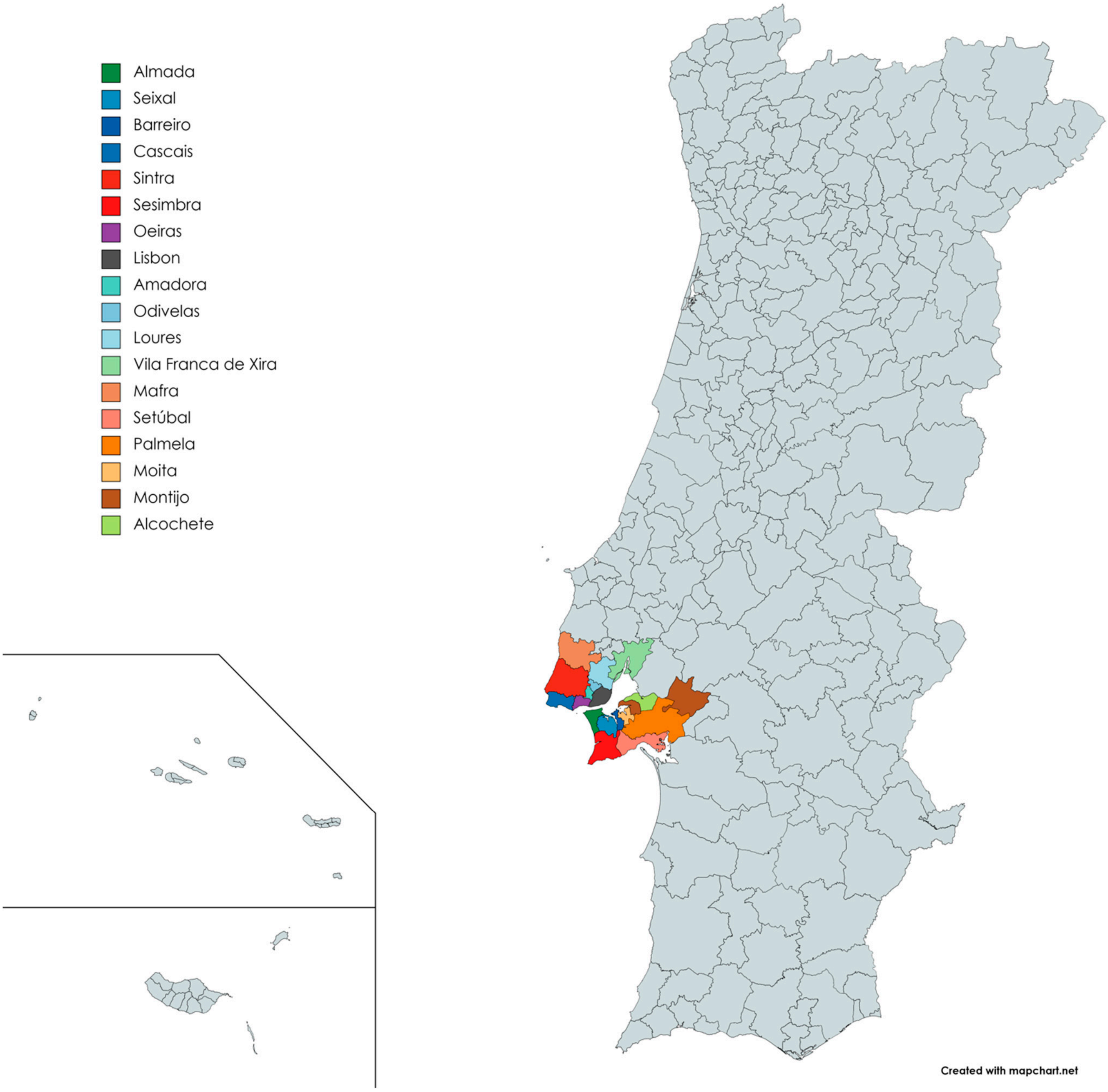


Figure 3. Lisbon Metropolitan area map. This map was created with MapChart [90].

Moreover, the Lisbon Metropolitan Area is crucial in driving Portugal's economy, serving as a hub for various industries such as finance, technology, tourism, commerce, and services. This dynamic economic landscape is further enhanced by multinational corporations, startups, and research institutions, contributing to the region's reputation as a centre of innovation and entrepreneurship [91]. Given the diverse economic composition, including industry, services, and tourism, studying the impact of ecological houses in this area offers a unique opportunity to examine their effects on different sectors of the economy.

In addition to Lisbon, the metropolitan area encompasses several municipalities, including Amadora, Oeiras, Cascais, Sintra, and Loures. These municipalities blend residential, commercial, and industrial areas, natural landscapes, and cultural attractions. Various stakeholders within the Lisbon Metropolitan Area, such as local authorities, residents, and businesses, hold distinct perspectives on adopting ecological houses. By conducting research in this region, valuable insights can be gained regarding how different stakeholders perceive the impact of ecological houses on economic development and identify critical success factors [91].

In the Lisbon Metropolitan Area, there has been a notable surge in the number of eco-friendly houses that meet high energy efficiency standards like A+, A, B, and B-, according to Koengkan and Fuinhas [71]. Specifically, there were only 8047 eco-friendly houses in 2014, but by 2020, this number had more than doubled to 16,881. In contrast, the number of non-eco-friendly houses with lower energy efficiency certifications, such as C, D, E, and F, was 32,874 in 2014. However, by 2020, this number decreased to 28,017, reflecting a positive trend towards eco-friendliness. (see Figure 4 below).

The Lisbon metropolitan area comprises various municipalities that have made significant strides towards eco-friendliness. The area's largest number of eco-friendly houses is in Lisbon, with 29,833 houses, followed by Cascais with 6585, Seixal with 6435, and Loures with 5324. Other municipalities with high numbers of eco-friendly houses include Odivelas, Sintra, Oeiras, Mafra, Almada, Setubal, Montijo, Amadora, Vila Franca de Xira, Sesimbra, Palmela, and Barreiro. However, some municipalities still have a long way to go to increase the number of eco-friendly houses. Alcochete has the lowest number of eco-friendly houses, with only 763, followed by Moita, with just 516. Regarding non-eco-friendly houses, the highest numbers are found in Lisbon, with 86,071; Sintra, 36,925; and Cascais, 21,161. Other municipalities with high numbers of non-eco-friendly houses include Almada, Oeiras, Amadora, Seixal, Loures, Setubal, Vila Franca de Xira, Barreiro, Odivelas, Mafra, Sesimbra, Palmela, Montijo, and Alcochete (see Figure 5 below).

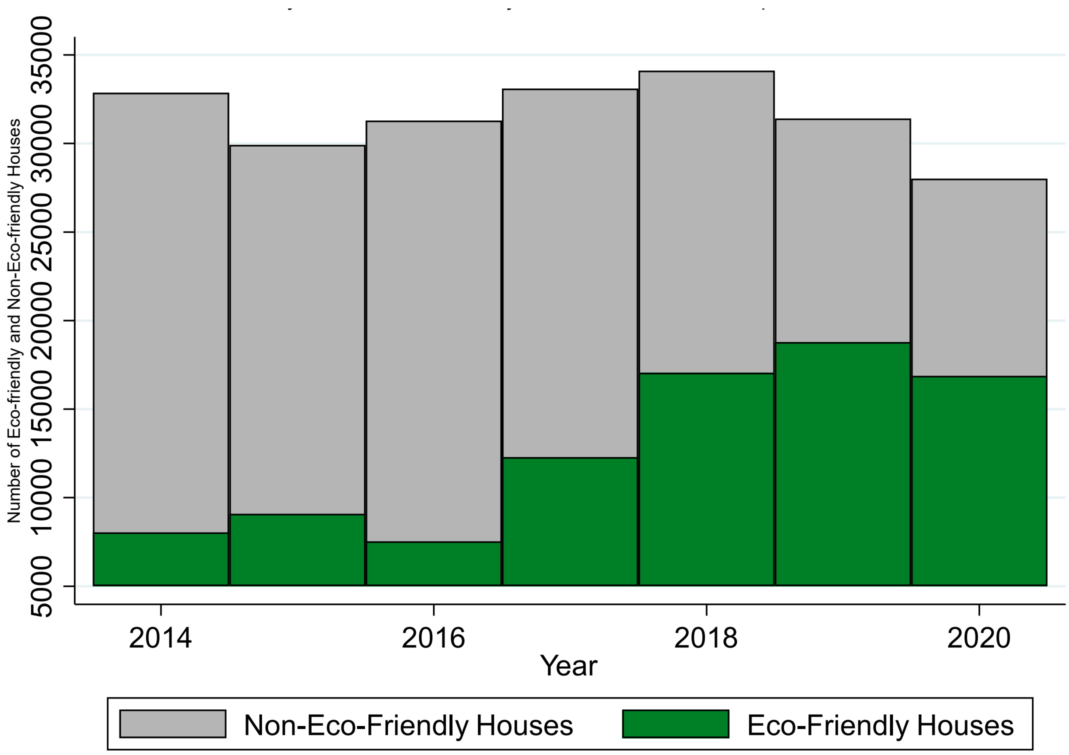


Figure 4. Number of Eco-friendly and Non-Eco-friendly houses in Lisbon Metropolitan Area from 2014 to 2020. This graph was created by data from SCE [92].

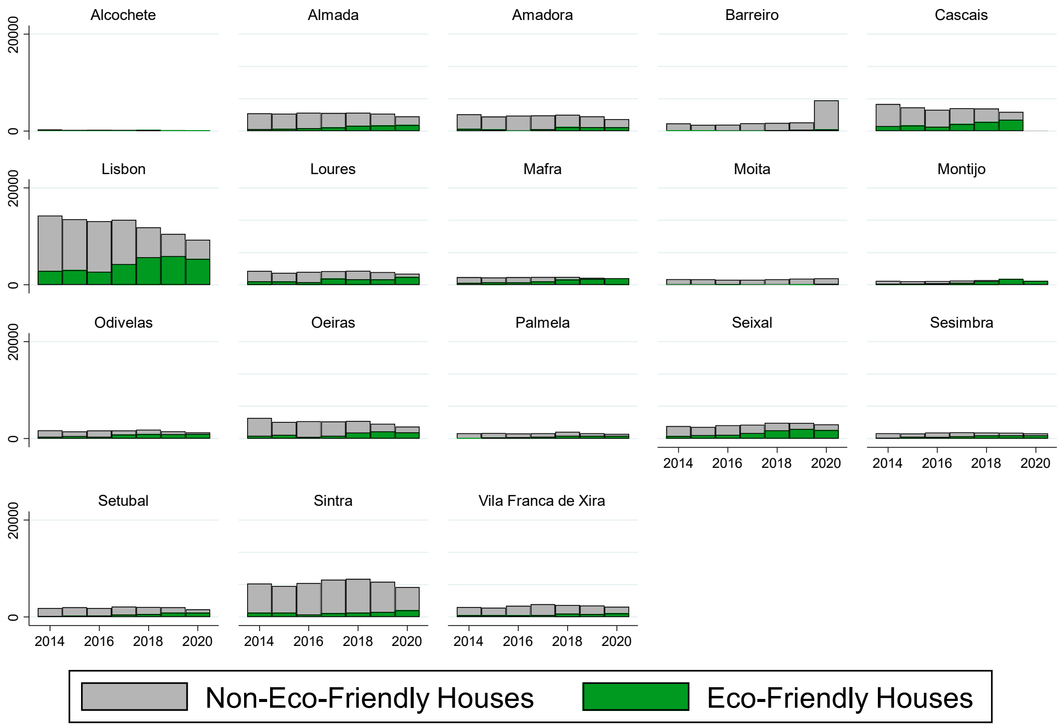


Figure 5. Number of Eco-friendly and Non-friendly houses in Lisbon Metropolitan Area Municipalities from 2014 to 2020. This graph was created by data from SCE [92].

In the Lisbon metropolitan area, the number of houses classified as "eco-friendly" has been on the rise since 2017, which can be attributed to the property boom occurring not only in this region but also throughout Portugal. The property market in Portugal grew by 50% in the same year [93].

Since 2017, this property boom has facilitated the construction of highly energy-efficient houses, classified as "eco-friendly". Moreover, it has also facilitated the reconstruction and revitalization of deteriorated houses with low energy efficiency, making them more environmentally sustainable. In the Lisbon metropolitan area, the number of completed dwellings for family housing in new constructions was 1132 in 2014. However, this number increased significantly, reaching 2883 by 2020 [94]. According to data from the National Institute of Statistics [95], the ratio of completed reconstructions to new constructions, expressed as the number of reconstructions completed per 100 new constructions (No.), was 1.5 in 2014. However, this ratio decreased significantly over the years and reached a value of 0.5 in 2020.

As previously mentioned, the surge in property demand in Portugal can be attributed to several factors, including tax incentives, tourism, affordable property prices, low-interest rates, political stability, social harmony, and a temperate climate [71]. Additionally, Portugal's swift economic recovery following the Troika intervention, which spanned from 2011–2014, played a significant role. The country experienced a real Gross Domestic Product (GDP) growth rate of 0.795% in 2014, 1.79% in 2015, 2.02% in 2016, 3.51% in 2017, 2.85% in 2018, and 2.68% in 2019, but the trend was interrupted in 2020 due to the COVID-19 pandemic, with a decline of 8.30% in the real GDP growth rate [96].

The economic growth experienced in Portugal between 2014 and 2019 directly and positively impacted the Lisbon metropolitan area's GDP per capita (base = 2016). In 2014, the GDP per capita was €27,831 (Euros), which increased to €28,373 in 2015, €28,876 in 2016, €29,682 in 2017, and €30,770 in 2018. By 2019, the GDP per capita had reached €32,029. Unfortunately, the COVID-19 pandemic 2020 led to a decline in the Lisbon metropolitan area's GDP per capita (base = 2016), falling to €29,291 [91].

Between 2014 and 2019, households in the Lisbon metropolitan area experienced an increase in GDP per capita, allowing them to acquire new high-energy efficiency dwellings and reconstruct and requalify deteriorated dwellings with low energy efficiency. This property boom in Lisbon and Portugal was influenced by increased credit agreements for the purchase, construction, and reconstruction of permanent or secondary dwellings during the rapid economic growth from 2014–2019. In 2014, credit agreements in the Lisbon metropolitan area for such purposes were €35,105.803 (Thousands) and reached €31,213.729 (Thousands) in value in 2019 [97]. Interest rates for housing credit were also reduced during this period, dropping from 3.19% in 2014 to 1.00% in 2020 [98].

Other factors may have contributed to the increase in the number of "eco-friendly" houses and reduction of "non-eco-friendly" houses in the Lisbon metropolitan area, including the implementation of energy efficiency policies for the residential sector in Portugal. According to Koengkan et al. [12], since 2006, five energy efficiency policies have been in force in Portugal. The first policy, implemented in 2006, revised the national RSECE building code and established strict standards for HVACs energy use. The second policy, implemented in 2007, established strict standards for space cooling, heating, water heating, ventilation, and lighting interior. The third policy, implemented in 2008, comprises a set of measures aiming at an increase in energy efficiency equivalent to about 10% of the final energy consumption. The fourth policy, implemented in 2013, established strict standards for energy efficiency conditions and the use of renewable energy systems to ensure the energy performance of buildings. The fifth policy, implemented in 2020, provides incentives to promote buildings' energy efficiency and decarbonization.

These national policies were established through various decrees and directives, including the Energy Performance of Buildings Directive and the Sustainable Buildings Directive, which set energy consumption reduction goals in 2020 and 2030. The introduction of these policies may have played a role in the reduction of the number of dwellings with low energy efficiency ratings in Portugal [76].

This investigation first identified the group of municipalities to determine the appropriate period for the empirical study. This investigation selected a time frame to provide sufficient data to meet the research objectives. Therefore, this study has chosen the period from 2014 to 2020 as the most suitable timeframe for this investigation.

The starting point of 2014 is appropriate because it aligns with the availability of data for the energy efficiency certificate ratings, which are critical components of the ECO_HOUSES and NON_ECO_HOUSES variables. These variables are a proxy of "eco-friendly" and "non-eco-friendly" houses, an essential aspect of our investigation. Likewise, this investigation chose 2020 as the endpoint for our study because it corresponds to the latest available data for some critical variables. For example, this investigation obtained GDP per capita data for all municipalities in the Lisbon metropolitan area until 2020. Additionally, this study could retrieve data on the number of completed dwellings in new constructions for family housing until 2020. Table 1 below provides a comprehensive overview of the variables used in this empirical investigation.

The use of dependent variable GDP as a proxy for economic development is commonly employed in economic research. GDP per capita is a widely used measure of a country's economic performance and is often used to indicate economic development. It represents the average income of individuals in a given population and is, therefore, a useful measure of the standard of living of a country's residents. In the context of this article, the dependent variable GDP is used to assess the impact of eco-friendly houses on economic development in the Lisbon metropolitan area. It is reasonable to use GDP per capita as a proxy for economic development in this context, as it broadly measures the region's economic performance, reflecting changes in income levels, employment rates, and economic growth.

Moreover, since the study investigates the relationship between eco-friendly houses and economic development, using GDP per capita as the dependent variable is justifiable. Changes in eco-friendly houses may impact economic development through multiple channels, such as energy consumption, employment, and household disposable income. GDP per capita provides a comprehensive measure that captures the net effect of these channels on economic development.

Table 1. Variables and sources.

Abbreviation	Variables	Source	QR Codes
	Dependent variable		
GDP	GDP (base = 2016) for each municipality. Indeed, this variable was built by the GDP of each region (25 NUTS III) × (population of municipality/population of the region (25 NUTS III)). This variable can serve as a proxy for economic development.	Constructed variable with data from INE [93]	
	Independent variables		
POLICIES	National policies for residential energy efficiency include regulations for HVAC systems, energy certificates, the National Energy Efficiency Action Plan, building certification, and the Environmental Fund's Sustainable Buildings program. These policies incentivize compliance with subsidies, loans, tax relief, funds, infrastructure, implementation aid, information, labelling, training, auditing, standards, monitoring, and obligation schemes. This variable was built in accumulated form, where each policy type that was implemented is represented by (1) accumulated over other policies throughout its useful life (In force) or end (e.g., 1, 1, 2, 2, 2, 3,3).	IEA [99]	
HOUSES_RECONS	Number of completed reconstructions per 100 completed new constructions.	INE [95]	
NEW_HOUSES	Number of completed dwellings in new constructions for family housing.	INE [94]	
ECO_HOUSES	"Eco-Friendly" Houses. This variable represents the total number of houses that have received high energy efficiency certificate ratings, such as A+, A, B, and B−. These ratings indicate that the houses use less energy and are more environmentally friendly than houses with lower ratings. Therefore, this variable can serve as a proxy for identifying the number of eco-friendly houses.	Constructed variable with data from SCE [92]	
NON_ECO-HOUSES	"Non-Eco-Friendly" Houses. This variable represents the total number of houses that have received low energy efficiency certificate ratings, such as C, D, E, and F. These ratings indicate that the houses use more energy and are less environmentally friendly than houses with higher ratings. Therefore, this variable can serve as a proxy for identifying the number of non-eco-friendly houses.	Constructed variable with data from SCE [92]	

Notes: This table was created by the authors.

The use of independent variables such as POLICIES, HOUSES_RECONS, NEW_HOUSES, ECO_HOUSES, and NON_ECO-HOUSES to explain the dependent variable GDP is economically justified as they have significant impacts on economic growth. Policies such as subsidies, loans, and tax relief can encourage investment in energy-efficient technologies, increasing household disposable income and job creation. Completed house reconstructions can lead to economic benefits such as job creation, increased demand for construction materials and services, and improved energy efficiency of existing housing stock.

An increase in the number of newly completed houses can have far-reaching effects on the economy, such as job creation, increased economic activity, and changes in consumer spending and property values. However, it is essential to consider the environmental impact of these houses, particularly in terms of their energy efficiency.

Eco-friendly houses, certified with high energy efficiency ratings (such as A+, A, B, and B−), can contribute to environmental sustainability, higher property values, and job creation. On the other hand, non-eco-friendly houses, which have low energy efficiency ratings (such as C, D, E, and F), can negatively impact environmental sustainability, household wealth, and the construction and energy efficiency industries.

By analyzing these independent variables, we can gain valuable insights into their potential impacts on economic development. This makes it economically justified to prioritize the construction of energy-efficient and eco-friendly houses, as they can benefit both the environment and the economy.

3.2. Method

This section will discuss three crucial aspects of our empirical analysis. First, we will showcase the preliminary tests conducted to evaluate the quality of our data and the assumptions required for our regression models. Second, we will delve into the OLS model regression with fixed effects, which enables us to isolate the impact of independent variables on the dependent variable while accounting for time-invariant individual or group characteristics. Finally, we will introduce the Method of Moments Quantile Regression (MM-QR) with fixed effects, which allows for a more flexible modelling of the conditional distribution of the dependent variable by estimating the conditional quantiles at various levels.

3.2.1. Preliminary Tests

The preliminary tests play a crucial role in determining the suitability of the variables used in the econometric model and in selecting the best model estimator. Therefore, before running the OLS with fixed effects and MM-QR estimators, it is necessary to perform a battery of tests to check for normality, correlation, multicollinearity, heteroscedasticity, and serial correlation. These tests include:

(i) Descriptive statistics: Provides summary statistics such as mean, standard deviation, minimum, maximum, and quartiles for each variable.
(ii) Histogram of variables: Displays the distribution of each variable, providing insights into its skewness, kurtosis, and potential outliers.
(iii) Pairwise Correlation [100]: Measures the strength and direction of the linear relationship between pairs of variables.
(iv) Skewness and kurtosis test for normality [101]: Tests whether the distribution of each variable is normal or not. The null hypothesis is that the variable is normally distributed.
(v) Collinearity Diagnostics [102]: Tests for multicollinearity among independent variables. High levels of multicollinearity can cause problems with the estimation and interpretation of coefficients.
(vi) Pesaran CD test [103]: Tests for cross-sectional dependence in panel data. The null hypothesis is that there is no cross-sectional dependence.
(vii) Fisher-type unit-root test [104]: Tests for the presence of a unit root in each variable. The null hypothesis is that there is a unit root.
(viii) Kao test for cointegration [105]: Tests for cointegration between pairs of variables. The null hypothesis is that there is no cointegration.
(ix) Pedroni test for cointegration [106]: Another cointegration test that allows for cross-sectional dependence. The null hypothesis is that there is no cointegration.

(x) Breusch-Pagan/Cook-Weisberg test for heteroskedasticity (e.g., [107,108]): Tests for the presence of heteroskedasticity in the error term. The null hypothesis is that there is no heteroskedasticity.
(xi) Wooldridge test for autocorrelation in panel data [109]: Tests for autocorrelation in the error term. The null hypothesis is that there is no autocorrelation.

These tests are widely used in the econometric literature to ensure the robustness and validity of the model (e.g., [110–112]).

3.2.2. The Ordinary Least Squares (OLS)

The OLS (ordinary least squares) model regression with fixed effects is a statistical method used to estimate the relationship between a dependent variable and one or more independent variables while controlling for fixed effects that are constant over time and vary across individuals or groups (e.g., [113,114]). The fixed effects capture the time-invariant heterogeneity of individuals or groups and control for omitted variables that could bias the estimates (e.g., [113,114]). The general equation for the OLS model regression with fixed effects is:

$$y_{it} = a_i + \beta_1 x1_{it} + \beta_2 x2_{it} + \cdots + \beta_k xk_{it} + \mu_{it} \quad (1)$$

where y_{it} is the dependent variable for individual i at time t, a_i is the individual fixed effect, $x1_{it}$, $x2_{it}$, k_{it} are the k independent variables for individual i at time t, $\beta_1, \cdots \beta_k$ are the corresponding coefficients, and μ_{it} is the error term.

The OLS model regression with fixed effects is a suitable method to identify the impact of independent variables POLICIES, HOUSES_RECONS, NEW_HOUSES, ECO_HOUSES, and NON_ECO-HOUSES on the dependent variable GDP, as it controls for time-invariant individual or group characteristics that affect both the dependent and independent variables. In the context of the housing sector, the fixed effects could capture the differences in housing policies, construction quality, and environmental regulations across municipalities, regions, or countries. By including these fixed effects, the OLS model regression can isolate the impact of the independent variables on the dependent variable while controlling for unobserved heterogeneity.

The present empirical investigation chose to employ two methods of OLS with fixed effects, namely FE Robust and FE D.-K, to estimate the relationship between the dependent and independent variables. FE Robust is a widely used method. Nevertheless, heteroskedasticity and cross-sectional dependence (spatial dependence or spatial regimes) in the data requires using a more robust estimator such as FE D.-K [115]. The FE D.-K method adjusts for heteroskedasticity and spatial dependence, improving the estimates' accuracy and reducing the potential for biased results. Therefore, the FE D.-K method is preferred in this investigation to ensure the estimates are reliable and robust.

3.2.3. The Method of Moments Quantile Regression (MM-QR)

The Method of Moments Quantile Regression (MM-QR) with fixed effects is a statistical method used to estimate the relationship between a dependent variable and one or more independent variables while controlling for fixed effects that are constant over time and vary across individuals or groups at different quantiles of the conditional distribution [116]. The MM-QR with fixed effects is an extension of the OLS model regression with fixed effects that allows for a more flexible modelling of the conditional distribution of the dependent variable by estimating the conditional quantiles of the dependent variable at different levels (e.g., [117,118]). The general equation for the MM-QR with fixed effects is:

$$Q\tau_{(y_{it})} = a_i + \beta_1 x1_{it} + \beta_2 x2_{it} + \cdots + \beta_k xk_{it} + \mu_{it} \quad (2)$$

where $Q\tau_{(y_{it})}$ is the τ-th quantile of the dependent variable y_{it} for individual i at time t, a_i is the individual fixed effect, $x1_{it}$, $x2_{it}$, k_{it} are the k independent variables for individual i at time t, $\beta_1, \cdots \beta_k$ are the corresponding coefficients, and μ_{it} is the error term.

In this investigation, we used the MM-QR with fixed effects to estimate the impact of independent variables POLICIES, HOUSES_RECONS, NEW_HOUSES, ECO_HOUSES, and NON_ECO-HOUSES on the dependent variable GDP at different quantiles of the conditional distribution (25th, 50th, 75th, and 90th). By estimating the conditional quantiles, this investigation can examine whether the effect of the independent variables on GDP varies across different levels of the distribution and whether the fixed effects play a role in shaping the relationship.

Indeed, this is a suitable method for this investigation as it allows for more flexible modelling of the conditional distribution of the dependent variable while controlling for time-invariant individual or group characteristics that affect both the dependent and independent variables. In the context of the housing sector, the MM-QR with fixed effects can provide insights into how different policies and housing types affect different population segments and whether the fixed effects play a role in shaping the impact.

Moreover, the MM-QR with fixed effects is particularly useful in cases where the OLS assumptions may not hold, such as heteroskedasticity, outliers, or non-normal error terms. It also allows for the control of unobserved heterogeneity by including fixed effects. In this investigation, the MM-QR with fixed effects serves as a robustness check to ensure the validity of the OLS results and to provide additional insights into the impact of the independent variables on different parts of the conditional distribution of the dependent variable. Overall, using the MM-QR with fixed effects as a robustness check enhances the rigour and reliability of the analysis.

Indeed, this empirical investigation used the econometric software **Stata 17.0**. The Stata commands used in this study included *sum*, *histogram*, *pwcorr*, *graph matrix*, *sktest, collin, xtcd, xtunitroot, xtcointtest kao, xtcointtest pedroni, hettest, xtserial, hausman, xtreg*, and *xtqreg*. These commands were used to realize the preliminary tests and the model estimations.

4. Empirical Results

This section presents the empirical results of the investigation. The first step taken in this study was to calculate the preliminary tests, which included the descriptive statistics of the variables under consideration. Table 2 below displays the descriptive statistics of the variables, namely GDP, POLICIES, HOUSES_RECONS, NEW_HOUSES, ECO_HOUSES, and NON_ECO_HOUSES, which are reported in natural logarithms.

Table 2. Descriptive statistics of variables.

Variables	Obs	Mean	Std. Dev.	Min	Max
LogGDP	126	15.88212	4.2190	12.9402	33.0508
LogPOLICIES	126	1.5566	0.2269	1.0986	1.7917
LogHOUSES_RECONS	126	0.4024	0.8003	−0.6668	3.5351
LogNEW_HOUSES	126	4.1286	1.1146	0.6931	6.1793
LogECO_HOUSES	126	6.0022	1.1382	0.6931	8.6864
LogNON_ECO_HOUSES	126	7.3893	0.9334	3.2958	9.5672

Notes: "Log" means variable in the natural logarithms; The Stata command *sum* was used in this test.

As can be seen in Table 2 above, the dependent variable LogGDP has a mean of 15.88212 and a standard deviation of 4.2190, indicating that there is a considerable amount of variability in the data. The minimum and maximum values of LogGDP are 12.9402 and 33.0508, respectively.

Indeed, the independent variable LogPOLICIES has a mean of 1.5566 and a relatively small standard deviation of 0.2269, indicating that the data points are relatively close to the mean. The minimum and maximum values of LogPOLICIES are 1.0986 and 1.7917, respectively. The independent variable LogHOUSES_RECONS has a mean of 0.4024 and a relatively large standard deviation of 0.8003, indicating that the data points are dispersed. The minimum and maximum values of LogHOUSES_RECONS are −0.6668 and 3.5351, respectively. The independent variable LogNEW_HOUSES has a mean of 4.1286 and a standard deviation of

1.1146. The minimum and maximum values of LogNEW_HOUSES are 0.6931 and 6.1793, respectively. The independent variable LogECO_HOUSES has a mean of 6.0022 and a standard deviation of 1.1382. The minimum and maximum values of LogECO_HOUSES are 0.6931 and 8.6864, respectively. Finally, the independent variable LogNON_ECO_HOUSES has a mean of 7.3893 and a standard deviation of 0.9334. The minimum and maximum values of LogNON_ECO_HOUSES are 3.2958 and 9.5672, respectively.

The second step is necessary to calculate the histogram of variables. The resulting histogram can be seen in Figure 6, which visually represents the distribution of the variables.

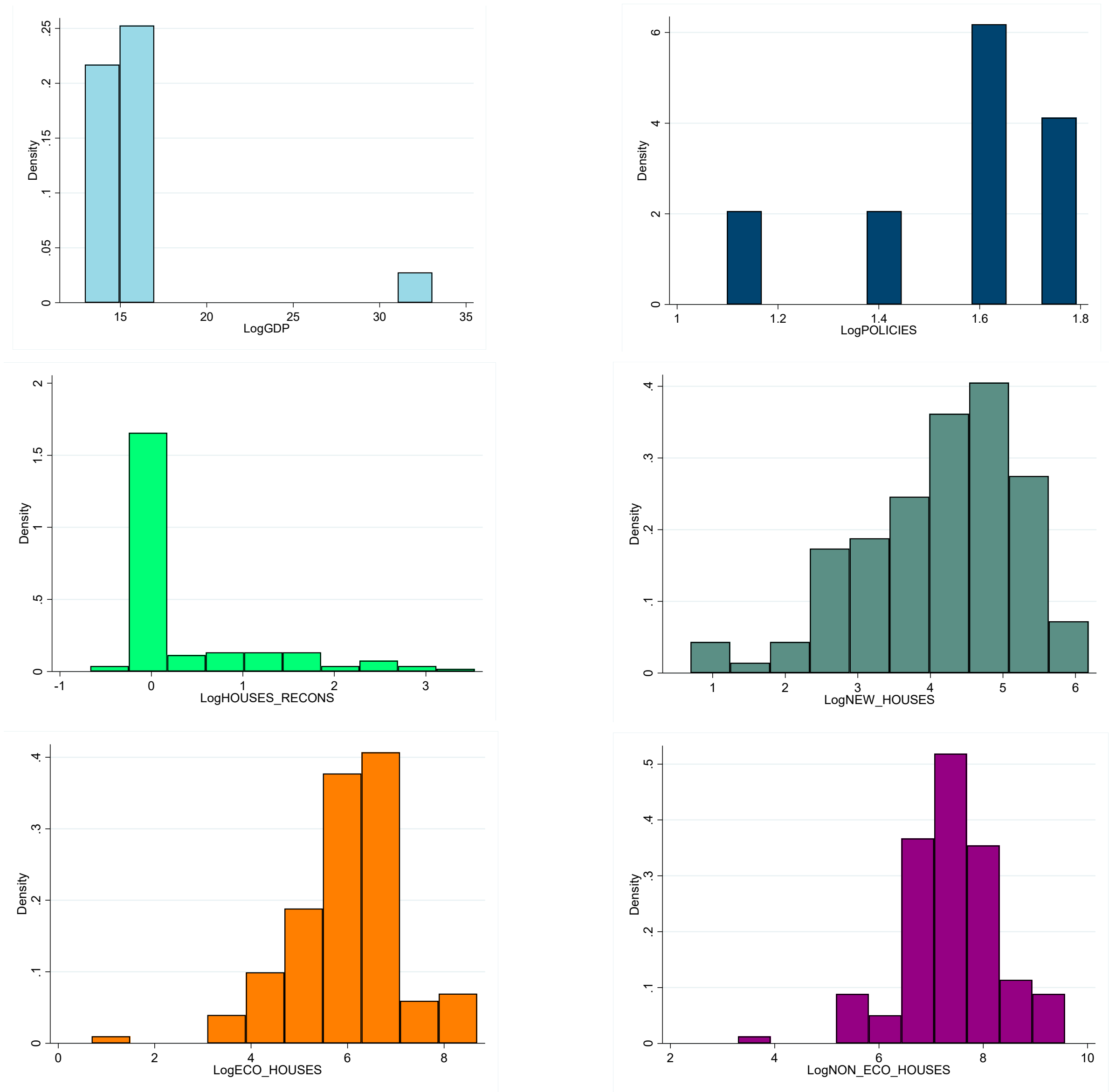


Figure 6. Histogram of variables. Notes: "Log" means variable in the natural logarithms; The Stata command *histogram* was used in this test.

The histograms reveal insights into the distribution of data for each variable. The dependent variable, LogGDP, is skewed to the left, indicating that there are more observations with larger values of LogGDP and fewer observations with smaller values. The independent variable, LogPOLICIES, is skewed to the right, suggesting that there are more observations with smaller values of LogPOLICIES and fewer observations with larger values. The independent variable, LogHOUSES_RECONS, is also skewed to the left, indicating that there are more observations with larger values of LogHOUSES_RECONS and fewer observations with smaller values.

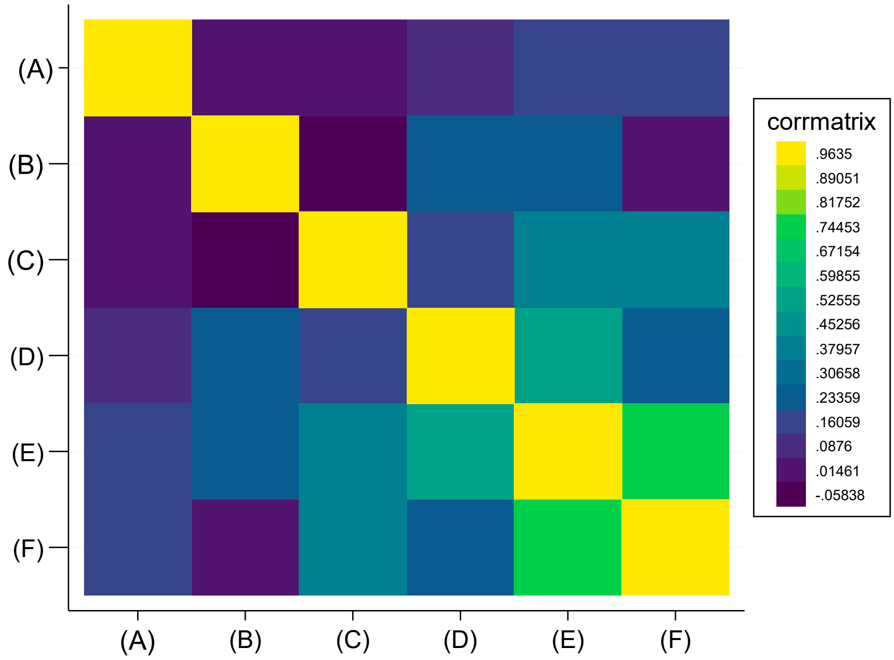
In contrast, the data for the independent variable, LogNEW_HOUSES, appears to be roughly symmetrical, suggesting that the observations are distributed relatively evenly across the range of values. Similarly, the data for the independent variable, LogECO_HOUSES, also appears to be roughly symmetrical, indicating that the observations are distributed relatively evenly across the range of values. Finally, the data for the independent variable, LogNON_ECO_HOUSES, is also roughly symmetrical, suggesting that the observations are distributed relatively evenly across the range of values.

The third step of this investigation involves calculating the Pairwise Correlation test for all variables included in the model. Table 3 below presents the results of the Pairwise Correlation test.

Table 3. Pairwise Correlation.

Pairwise Correlation						
Variables	**(A)**	**(B)**	**(C)**	**(D)**	**(E)**	**(F)**
LogGDP (A)	1.000					
LogPOLICIES (B)	0.0150	1.000				
LogHOUSES_RECONS (C)	0.0128	−0.0949	1.000			
LogNEW_HOUSES (D)	0.0813	0.2378 ***	0.1600 *	1.000		
LogECO_HOUSES (F)	0.1258	0.2421 **	0.3636 ***	0.5546 ***	1.000	
LogNON_ECO_HOUSES (E)	0.1713 **	−0.0079	0.397 ***	0.2247 **	0.7445 ***	1.000

Pairwise Correlation Matrix



Notes: ***, **, * denote statistically significant at 1%, 5%, and 10% levels, respectively; "Log" means variable in the natural logarithms; The Stata command *pwcorr* was used in this test.

Table 3 above displays the Pairwise correlation coefficients among the six variables under investigation: LogGDP (A), LogPOLICIES (B), LogHOUSES_RECONS (C), LogNEW_HOUSES (D), LogECO_HOUSES (E), and LogNON_ECO_HOUSES (F). The correlation coefficients are presented in the cells where the two variables intersect. Based on the results presented in this table, the highest correlation coefficient is observed between LogECO_HOUSES and LogNON_ECO_HOUSES, with a coefficient of 0.7445. This result suggests a strong positive correlation between these two variables. Conversely, the correlation coefficient between LogGDP and LogPOLICIES is very low, at 0.0150, indicating a weak positive correlation between these variables. Indeed, the results from the Pairwise correlation matrix above confirm these results.

The fourth step of this investigation involves conducting a Skewness and Kurtosis test to assess the normality of all variables included in the model. The results of the Skewness and Kurtosis test for normality are presented in Table 4 below.

Table 4. Skewness and kurtosis test for normality.

Variables	Skewness/Kurtosis Tests for Normality					Obs
	Pr (Skewness)	Pr (Kurtosis)	adj chi2(2)	Statistic		
LogGDP	0.0000	0.0000		0.0000	***	126
LogPOLICIES	0.0001	0.7845	12.72	0.0017	***	126
LogHOUSES_RECONS	0.0000	0.0001	42.63	0.0000	***	126
LogNEW_HOUSES	0.0008	0.1246	11.58	0.0031	***	126
LogECO_HOUSES	0.0005	0.0002	20.80	0.0000	***	126
LogNON_ECO_HOUSES	0.0104	0.0004	15.49	0.0004	***	126

Notes: *** denotes statistical significance at 1% level; "Log" means variable in the natural logarithms; The Stata command *sktest* was used in this test.

Table 4 above presents the results of skewness and kurtosis tests for normality on six variables (e.g., LogGDP, LogPOLICIES, LogHOUSES_RECONS, LogNEW_HOUSES, LogECO_HOUSES, and LogNON_ECO_HOUSES) with 126 observations. The Skewness test is used to determine if the distribution of a variable is symmetrical or skewed. The table above shows that all variables have skewness values close to 0, indicating their distributions are approximately symmetrical. However, the LogNON_ECO_HOUSES variable has a skewness value of 0.0104, slightly higher than the other variables. The Kurtosis test is used to determine if the distribution of a variable is normal or has heavy tails (leptokurtic) or light tails (platykurtic). The table shows that all variables have kurtosis values close to 0, indicating their distributions are approximately normal. However, the LogPOLICIES variable has a kurtosis value of 12.72, which is higher than the other variables. This finding suggests that the distribution of LogPOLICIES may have heavier tails than the other variables. Overall, the results suggest that the variables in the study are approximately normally distributed. The statistical significance (at the 1% level) of the chi-square test of normality indicates that these distributions are significantly different from normality, but the deviations from normality are likely small.

A collinearity diagnostics test was conducted as the fifth step of this investigation. The results of this test are presented in Table 5 below.

Table 5. Collinearity Diagnostics.

Variables	VIF	SQRT VIF	Tolerance	R-Squared	Eigenval		Eigenval Index
LogGDP	1.23	1.11	0.8100	0.1900	1	6.1252	1.0000
LogPOLICIES	1.21	1.10	0.8245	0.1755	2	0.7520	2.8539
LogHOUSES_RECONS	1.29	1.14	0.7746	0.2254	3	0.0597	10.1332
LogNEW_HOUSES	1.86	1.36	0.5388	0.4612	4	0.0364	12.9780
LogECO_HOUSES	3.87	1.97	0.2582	0.7418	5	0.0146	20.4893
LogNON_ECO_HOUSES	2.43	1.56	0.4117	0.5883	6	0.0093	25.6052
Mean VIF		1.98			7	0.0029	46.2613
Condition Number						46.2613	
Eigenvalues & Cond Index computed from scaled raw sscp (w/intercept) Det (correlation matrix)						0.1576	

Notes: "Log" means variable in the natural logarithms; The Stata command *collin* was used in this test.

Table 5 above presents the results of the collinearity diagnostics test, which indicate no significant collinearity among the predictor variables. The VIF values range from 1.23 to 3.87, with an average of 1.98, suggesting a moderate correlation among the predictor variables. The square root of the VIF values ranges from 1.11 to 1.97, which further supports this finding. Additionally, the tolerance values range from 0.26 to 0.82, indicating that each predictor variable uniquely contributes to the model. The R-squared values range from 0.26 to 0.82, suggesting that each predictor variable significantly contributes to the model. The condition number is 46.2613, indicating no significant collinearity among the predictor variables. Lastly, the determinant value 0.1576 suggests that the predictor variables are not highly correlated.

As the investigation progresses, the sixth step involves conducting the Pesaran CD test to analyze the data further. The results of this test are presented in Table 6 below, providing important insights for the ongoing research.

Table 6. Pesaran CD test.

Variables	CD-Test	*p*-Value	Obs
LogGDP	32.44	***	126
LogPOLICIES	32.46	***	126
LogHOUSES_RECONS	N.A		126
LogNEW_HOUSES	15.97	***	126
LogECO_HOUSES	26.45	***	126
LogNON_ECO_HOUSES	8.74	***	126

Notes: *** denotes statistical significance at 1% level; "Log" means variable in the natural logarithms; The Stata command *xtcd* was used in this test; N.A denotes unavailable.

The results from Table 6 above indicate the presence of cross-sectional dependent in the variables in the residuals of the panel data regression for most of the variables, indicating that the assumption of cross-sectional independence may not hold. Moreover, for the variable LogHOUSES_RECONS, the CD-test statistic is not reported, which means that the test could not be performed due to missing observations.

The seventh step in the investigation is conducting a panel unit-root test to examine the data further. The results of this analysis are presented in Table 7 below, which displays the outcomes of a Fisher-type unit-root test. These findings will provide valuable information for the research progress.

Based on the results presented in Table 7 above, it can be observed that the variables LogGDP, LogECO_HOUSES, and LogNON_ECO_HOUSES, all measured in natural logarithms, are non-stationary. Similarly, LogPOLICIES and LogNEW_HOUSES show boundary behaviour between I(0) and I(1). On the other hand, the variable LogHOUSES_RECONS is stationary, indicating that it does not exhibit a trend or a unit root. Furthermore, when considering the variables in their first-difference form, the test shows that dLogGDP and dLogPOLICIES are non-stationary, while dLogECO_HOUSES displays boundary behaviour between I(0) and I(1). However, the variables dLogNEW_HOUSES and dLogNON_ECO_HOUSES are stationary, indicating that they do not possess a unit root and are thus time-invariant.

When dealing with non-stationary variables, examining the possibility of cointegration is essential. Therefore, the eighth step of this investigation involves conducting a cointegration test. This test aims to identify any long-term relationships between the variables under analysis. The results from the Kao and Pedroni tests for cointegration are presented in Table 8 below, providing essential insights into the relationship between the variables.

The Kao test for cointegration indicates strong evidence to reject the null hypothesis of no cointegration between the variables at a 1% significance level. The Dickey-Fuller t statistic is -4.7917 (*p*-value of 0.0000), and the unadjusted Dickey-Fuller t statistic is -7.8173 (*p*-value of 0.0000). However, cointegration tests provide statistical evidence and should be interpreted with economic reasoning and other empirical evidence. When examining the stationary variables, the Kao test results show that the *p*-values of all the statistics are below the significance level of 0.05, except for the Modified Dickey-Fuller t statistic. Therefore, there is not enough evidence to conclude that there is cointegration between the variables.

Table 7. Fisher-type unit-root test.

Variables	Fisher-Type Unit-Root Test (Based on Phillips-Perron Tests)				
	Without Trend			With Trend	
	Lags	Inverse Normal (Z)		Inverse Normal (Z)	
LogGDP	0	8.2056		0.3372	
	1	8.0925		0.1451	
LogPOLICIES	0	−8.5486	***	9.5038	
	1	−10.4421	***	10.8778	
LogHOUSES_RECONS	0	−5.8195	***	−6.6265	***
	1	−6.0145	***	−7.9411	***
LogNEW_HOUSES	0	0.0986		−4.5015	***
	1	0.0657		−6.2746	***
LogECO_HOUSES	0	2.2657		1.9285	
	1	2.6838		1.6228	
LogNON_ECO_HOUSES	0	4.3463		6.0491	
	1	3.8087		5.4698	
dLogGDP	0	0.0313		8.5471	
	1	0.2217		9.7752	
dLogPOLICIES	0	3.8931		0.1438	
	1	5.4022		−0.0773	
dLogHOUSES_RECONS	0	−9.9940		−4.3266	
	1	−11.1357	***	−4.6370	***
dLogNEW_HOUSES	0	−8.5165	***	−3.3044	***
	1	−9.9904	***	−5.6215	***
dLogECO_HOUSES	0	−3.2993	***	0.2991	
	1	−3.2195	***	−0.3345	
dLogNON_ECO_HOUSES	0	1.0892	***	−4.7146	***
	1	0.4446	***	−7.4530	***

Notes: ***, denotes statistically significant at 1% level, respectively; "Log" means variable in the natural logarithms; The Stata command *xtunitroot* was used in this test.

Table 8. Kao and Pedroni tests for cointegration.

Kao Test for Cointegration	Statistic	*p*-Value	
Modified Dickey-Fuller t	1.0130	0.1555	
Dickey-Fuller t	−4.7917	0.0000	***
Augmented Dickey-Fuller t	−0.8083	0.2095	
Unadjusted modified Dickey-Fuller t	−2.7854	0.0027	**
Unadjusted Dickey-Fuller t	−7.8173	0.0000	***
Pedroni Test for Cointegration	**Statistic**	***p*-Value**	
Modified Phillips-Perron t	3.9430	0.0000	***
Phillips-Perron t	1.9730	0.0242	**
Augmented Dickey-Fuller t	−3.0849	0.0010	**

Notes: ***, ** denotes statistically significant at 1% and 5% levels, respectively; "Log" means variable in the natural logarithms; The Stata commands *xtcointtest kao,* and *xtcointtest pedroni* were used in this test.

The Pedroni test was also computed to confirm the Kao test results. The results indicate evidence of cointegration between the variables. The Modified Phillips-Perron t statistic is 3.9430 (greater than the critical value for the 5% significance level), and the Phillips-Perron t statistic is 1.9730 (also greater than the critical value at the 5% significance level). However, the Augmented Dickey-Fuller t statistic is −3.0849 (less than the critical value for a 1% significance level), indicating rejection of the null hypothesis of no cointegration. Based on the Pedroni test, it can be concluded that there is evidence of cointegration between the variables, suggesting a long-term relationship and a common trend.

The ninth step of this investigation involves checking for the presence of heteroskedasticity and autocorrelation in panel data. Table 9 displays the results of the Breusch-Pagan/Cook-Weisberg test for heteroskedasticity and the Wooldridge test for autocorrelation in panel data.

Table 9. Breusch-Pagan/Cook-Weisberg test for heteroskedasticity and Wooldridge test for autocorrelation in panel data.

Breusch-Pagan/Cook-Weisberg test for heteroskedasticity
chi2(1) = 80.52 ***
Wooldridge test for autocorrelation in panel data
F (1, 17) = 177.631 ***

Notes: *** denotes statistical significance at 1% level; The Stata commands *hettest* and *xtserial* were used in this test.

The results of the Breusch-Pagan/Cook-Weisberg test for heteroskedasticity, presented in Table 9, indicate that the chi-squared test statistic with one degree of freedom is 80.52, with a *p*-value of 0.0000. These results provide strong evidence against the null hypothesis of constant variance and suggest the presence of heteroskedasticity in the data. Similarly, the Wooldridge test for autocorrelation in panel data, also reported in Table 9, shows a statistic of F (1,17) = 177.631, with a *p*-value of 0.0000. These results provide strong evidence against the null hypothesis, indicating the presence of first-order autocorrelation in the panel data.

This investigation's tenth and final preliminary test examines the presence of fixed and random effects in the econometric model. The results of the Hausman test can be found in Table 10 below.

Table 10. Hausman test.

Models	chi2(5)	Prob.	
	117.60	0.0000	***

Notes: *** denotes statistically significant at 1% level; The Stata command *hausman* was used in this test.

The results of the Hausman test indicate that the test statistic is 117.60 with a *p*-value of 0.0000, providing strong evidence against the null hypothesis. As a result, we can conclude that the coefficients in the fixed and random effects models differ significantly. Based on these results, the fixed effects model is preferred over the random effects model.

After completing the preliminary tests, the next step is calculating the regression of OLS with fixed effects and MM-QR with fixed effects. The results of OLS with fixed effects, namely FE Robust and FE D.-K, can be found in Table 11 below. These methods were used to estimate the relationship between the dependent and independent variables. Additionally, Table 11 includes the results of the MM-QR with fixed effects, which serves as a robustness check.

Table 11 presents the regression analysis results using OLS with fixed effects. The analysis indicates that the independent variable LogPOLICIES has a positive impact of 0.1578 on the dependent variable LogGDP. This finding suggests that subsidies, loans, and tax relief can encourage homeowners to invest in energy-efficient technologies, boosting household disposable income and contributing to economic growth. Implementing infrastructure and aid programs can create job opportunities, while monitoring and obligation schemes can improve environmental sustainability and economic competitiveness.

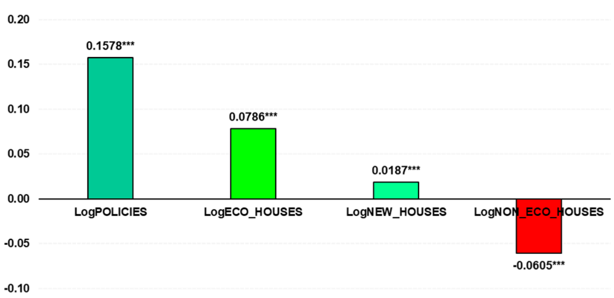
However, the econometric model suggests that the independent variable LogHOUSES _RECONS is statistically insignificant, meaning that this variable does not have a significant impact on the dependent variable. On the other hand, the independent variable

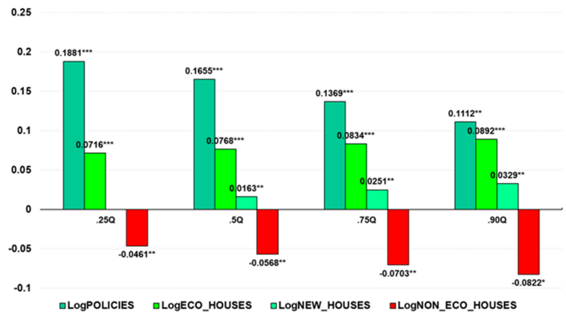
LogNEW_HOUSES has a positive impact of 0.0187 on the dependent variable LogGDP. Increasing the number of new constructions can lead to economic benefits, such as job creation and increased demand for construction materials and services. Additionally, new constructions can stimulate economic activity by increasing the housing supply, property values, household disposable income, and consumer spending.

Table 11. Results of OLS with fixed effects and MM-QR.

Independent Variables	Main Model			Robustness Check			
	OLS with Fixed Effects			MM-QR			
	Dependent Variable (LogGDP)			Dependent Variable (LogGDP)			
	Estimators			Quantiles			
	FE	FE Robust	FE. D.-K	0.25 Q	0.5 Q	0.75 Q	0.90 Q
LogPOLICIES	0.1578 ***	***	***	0.1881 ***	0.1655 ***	0.1369 ***	0.1112 **
LogHOUSES_RECONS	0.0027			0.0023	0.0026	0.0029	0.0033
LogNEW_HOUSES	0.0187 ***	**	**	0.0093	0.0163 **	0.0251 **	0.0329 **
LogECO_HOUSES	0.0786 ***	***	***	0.0716 ***	0.0768 ***	0.0834 ***	0.0892 ***
LogNON_ECO_HOUSES	−0.0605 ***	−0.0605 ***	−0.0605 ***	−0.0461 **	−0.0568 **	−0.0703 **	−0.0822 *
Constant	15.3949 ***	***	***	N.A	N.A	N.A	N.A
Obs	126	126	126	126	126	126	126

Graphical depiction of the impacts





Notes: ***, **, * denote statistically significant at 1%, 5%, and 10% levels, respectively; "Log" means variable in the natural logarithms; N.A denotes unavailable; The Stata commands *xtreg*, and *xtqreg* were used.

Furthermore, the analysis shows that the independent variable LogECO_HOUSES has a positive impact of 0.0786 on the dependent variable LogGDP. Increasing eco-friendly houses can lead to economic benefits, such as lower energy consumption, reduced carbon emissions, and improved environmental sustainability, contributing to overall economic growth. Additionally, eco-friendly houses may have higher property values, increasing household wealth and disposable income and creating jobs in the energy efficiency and construction industries.

Finally, the independent variable LogNON_ECO_HOUSES has a negative impact of −0.0605 on the dependent variable LogGDP. Increasing the number of non-eco-friendly houses can lead to negative economic effects, such as higher energy consumption, increased carbon emissions, and reduced environmental sustainability, which can hinder overall economic growth. Additionally, non-eco-friendly houses may have lower property values, decreasing household wealth and disposable income and negatively impacting the construction and energy efficiency industries. The graph depicting OLS regression can, with fixed effects, be found in Appendix A.

The robustness check using MM-QR confirms the results from OLS with fixed effects. Specifically, the results in Table 11 indicate that the independent variable LogPOLICIES positively impacts the dependent variable in all quantiles. The independent variable LogHOUSES_RECONS is statistically insignificant in all quantiles, suggesting that this variable does not have a significant impact on the dependent variable. The independent variable LogNEW_HOUSES positively impacts the 50th, 75th, and 90th quantiles, indicating that an increase in the number of new constructions can lead to economic benefits across different income levels. The independent variable LogECO_HOUSES has a positive impact in all quantiles, highlighting the economic benefits of eco-friendly housing. Finally, the independent variable LogNON_ECO_HOUSES negatively impacts all quantiles, indicating the negative economic impact of non-eco-friendly housing. Therefore, the MM-QR results provide additional evidence supporting the robustness of the results from OLS with fixed effects. The graph depicting MM-QR regression can be found in Appendix B.

Indeed, the results of the OLS model regression presented in Table 11 above are succinctly summarized in Figure 7 below.

In the following section, this investigation will discuss the results of the empirical investigation that were obtained.

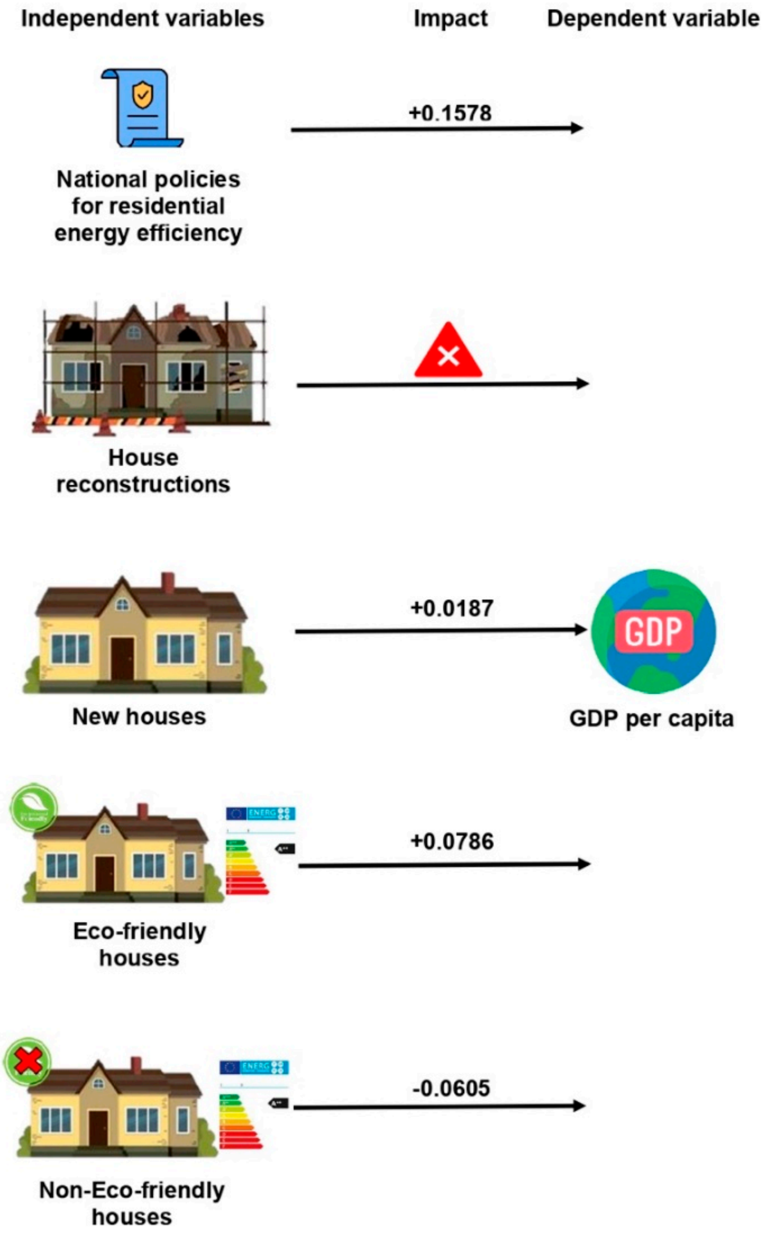


Figure 7. Summary of empirical results. This figure was created by the authors.

5. Discussion

This section will present possible explanations for the results that were found. In the literature, several authors (e.g., [119–121]) have found a positive impact of national policies for residential energy efficiency on economic growth.

Indeed, this positive impact can occur in several ways. First, these policies can stimulate demand for energy-efficient products and services, creating new markets and business opportunities. This situation can create new jobs, especially in the construction and energy sectors, and attract regional investments [120]. Second, improving energy efficiency in residential buildings can reduce household energy bills, freeing up resources that can be spent on other goods and services. It can increase household disposable income and consumption, which can, in turn, stimulate economic growth through the multiplier effect [119]. Third, energy efficiency policies can reduce greenhouse gas emissions, which can positively impact the environment and human health, leading to productivity gains and lower healthcare costs. Additionally, reducing energy consumption can help to reduce dependence on imported energy, improving energy security and reducing the trade deficit (e.g., [72,121]). Finally, energy efficiency policies can also help improve the quality of housing and reduce energy poverty, which can positively impact social welfare and equality ([119,120]).

The lack of impact of house reconstructions on economic growth in the Lisbon metropolitan municipalities can be explained by several factors. One factor is the high cost of reconstruction, which may not generate enough economic activity to offset the costs. Moreover, the benefits of reconstruction may be concentrated among homeowners and construction firms, while the costs may be spread among a broader population. Additionally, the economic benefits of energy-efficient renovations may be limited by high upfront costs and long payback periods, according to studies by Economidou et al. [122] and Economidou and Bertoldi [123].

Another possible explanation for the lack of impact of house reconstructions on economic growth is that they may not address underlying economic challenges in the region, such as unemployment, income inequality, or inadequate infrastructure. In some cases, investments in house reconstructions may even exacerbate these issues by displacing low-income residents and contributing to gentrification. The European Investment Bank [39] also found that the economic benefits of building renovations may be offset by financing costs, particularly for low-income households.

However, the impact of house reconstruction on economic growth may vary depending on local factors such as the state of the housing market, the availability of financing, and the specific goals of the reconstruction project. Some studies and reports, such as Savills [83], Olga and Antonios [124], and Giang and Pheng [125], have found that house reconstructions can generate significant economic benefits, particularly in areas with high levels of blight and disinvestment. Sustainable and energy-efficient reconstruction projects may also provide long-term economic benefits through reduced energy costs and improved environmental sustainability (e.g., [43,55]).

The positive impact of new houses on economic growth has been found by some authors in the literature (e.g., [79]). One possible explanation for this positive impact is related to the multiplier effect that construction activity can have on the local economy. When new houses are built, they require inputs from various sectors, such as construction materials, labour, and professional services. It generates economic activity and employment opportunities in those sectors, generating additional spending and employment throughout the local economy. New houses can attract residents and businesses, leading to additional economic benefits such as increased consumer spending, job creation, and tax revenue. In addition, new houses may contribute to revitalising blighted areas and increase the overall attractiveness of the region for investment and development [79].

A study by the National Association of Home Builders found that each new house built generates an average of 2.97 jobs for one year and $111,000 in taxes and fees for state and local governments [79]. Additionally, a study by Hoffman [126] found that housing construction significantly contributes to economic growth in metropolitan areas, particularly during periods of economic recovery. The existing literature suggests that green or eco-friendly houses can promote economic growth, as noted by several authors (e.g., [29,127]).

There are several economic explanations for the positive impact of eco-friendly houses or greenhouses on economic growth in the Lisbon metropolitan municipalities. One explanation is that eco-friendly houses can reduce energy consumption, lowering energy costs for homeowners and businesses. This, in turn, can lead to increased disposable income, which can be spent on other goods and services, ultimately stimulating economic growth (e.g., [30,32]). According to a study by the European Environment Agency, the adoption of energy-efficient measures in buildings can result in energy savings of up to 50% and provide significant economic benefits through reduced energy bills and increased economic activity [31].

Additionally, eco-friendly houses may increase property values, attracting investment and development to the area [28]. This idea is also shared by the United Nations Environment Programme (UNEP) [127], where eco-friendly buildings can lead to cost savings for homeowners and businesses and increased property values and rental rates. These economic benefits can contribute to overall economic growth. A study by the University of California, Berkeley found that green-certified buildings had a higher sale price per square foot than non-, green-certified buildings, with the price premium ranging from 3.5% to 1,3% depending on the certification level [33]. This increase in property values can lead to increased property tax revenues for municipalities, which can be used to fund public services and infrastructure.

Moreover, using green technologies in eco-friendly houses can create new business opportunities and jobs, further contributing to economic growth. For example, installing and maintaining solar panels, energy-efficient HVAC systems, and other green technologies require skilled labour, providing opportunities for job creation and economic activity. A report by the International Renewable Energy Agency [128], found that the renewable energy industry employed over 11 million people worldwide in 2018, with the potential for significant job growth in the coming years [128]. This viewpoint is also shared by Singh et al. [34], where eco-friendly buildings can positively impact employee productivity and well-being, leading to economic benefits for businesses. This includes reduced healthcare costs and increased productivity, which can contribute to economic growth. Indeed, according to Wei and Zhang [29] and European Commission [49], eco-friendly buildings can contribute to job creation, increased economic activity in the construction sector, reduced energy costs, and increased property values. These economic benefits can have a positive impact on overall economic growth.

Another possible explanation is that eco-friendly houses may contribute to a more sustainable and resilient local economy. By reducing dependence on fossil fuels and promoting renewable energy sources, eco-friendly houses can help mitigate climate change's impacts and reduce vulnerability to energy price fluctuations. This can lead to a more stable economic environment conducive to long-term economic growth. A Global Commission on the Economy and Climate (GCEC) study found that investing in low-carbon and sustainable infrastructure could generate $26 trillion in economic benefits worldwide by 2030 [129]. The explanation provided above confirms Hypothesis (1) presented in the introduction, which suggests that eco-friendly or greenhouses/buildings positively impact the economic development of the Lisbon Metropolitan area. Therefore, this further supports the notion that sustainable construction practices can contribute to the growth and prosperity of the region.

Finally, some authors have found that non-friendly or non-greenhouses cause a negative impact on economic growth [49]. Non-friendly or non-greenhouses can have a negative impact on economic growth in the Lisbon metropolitan municipalities due to several economic factors. Firstly, non-green buildings are less energy-efficient, leading to higher energy costs for homeowners and businesses. It can reduce disposable income and limit spending on other goods and services, ultimately dampening economic growth (e.g., [130,131]). This idea is shared by Rosenow et al. [132] and Brounen et al. [133], where the authors found that buildings with poor energy efficiency can result in higher energy costs for homeowners and businesses, reducing disposable income and limiting spending on other goods and services.

Additionally, non-green buildings may negatively impact health and well-being, resulting in increased healthcare costs and reduced employee productivity [34]. Indeed, this point of view is shared by Wyon [134], where the authors found that inefficient buildings and poor indoor air quality can result in increased healthcare costs and reduced worker productivity, negatively impacting economic growth.

Furthermore, non-green buildings may contribute to climate change and associated economic costs, such as increased frequency and severity of natural disasters, which can damage property and infrastructure and disrupt economic activity [49]. The cost of climate change impacts on the economy is projected to be significant, with estimated costs of climate change for the global economy ranging from 2% to 10% of GDP by 2100 [135].

6. Conclusions and Policy Implications

The impact of eco-friendly houses on economic development in 18 municipalities Lisbon metropolitan area was studied using data from 2014 to 2020. The analysis was performed through ordinary least squares with fixed effects that revealed (i) national policies promoting residential energy efficiency have a positive impact on economic development; (ii) policies like subsidies, loans, and tax relief encourage homeowners to invest in energy-efficient technologies, boosting household disposable income and contributing to economic growth; (iii) an increase in the number of new constructions has a positive impact on economic development, leading to job creation and increased demand for construction materials and services; (iv) an increase in the number of eco-friendly houses can result in reduced energy consumption, leading to lower energy costs for homeowners and businesses and ultimately stimulating economic growth; and (v) an increase in the number of non-eco-friendly houses materializes in negative economic growth impacts. Furthermore, the robustness check using the method of moments quantile regression has confirmed the findings from ordinary least squares with fixed effects.

6.1. Policy Implications

Portugal has a huge potential to gain with eco-friendly houses. First, however, policymakers must take advantage of creating a regulatory environment that can allow building new houses to benefit from leaping several stages and taking advantage of the availability of construction-improved technologies.

Given the challenge of financing the massif cost of the energy transition from fossil to renewable energy sources is also vital to improve societies' energy efficiency to reduce the energy demand. Accordingly, policymakers should exploit the public's perception of the reduction in energy bills from living in eco-friendly houses to motivate people to bear the initial costs of new buildings and the reconstruction of eco-friendly dwellings.

A factor that policymakers can take advantage of is that less local pollution from using fossil fuels in warming houses increases these locations' attractiveness and property value. Accordingly, to initiate or stimulate the transformation of traditional to eco-friendly areas, policymakers can carry out rehabilitation work in these areas.

Policymakers should not forget that cities compete between them to attract economic activity. Therefore, the attractiveness of cities is fundamental in their capacity to attract people and grow economic activity. Furthermore, increasing eco-friendly houses makes cities environmentally friendly, a major asset in this attraction.

Lisbon metropolitan area (and Portugal as a whole) has suffered from a persistent property price increase. Consequently, policymakers should be cautious and prepared to handle a possible bursting of the property speculative bubble. Furthermore, given their foremost consequences, policymakers must be cautious with the bursting of property bubbles to protect social, economic, and financial stability, prevent social inequality, and minimize regulatory risks.

Another factor that policymakers should be aware it is the role of immigration in the construction sector. This situation is especially acute in countries like Portugal, where the availability of a young workforce is scarce. Therefore, policymakers ought to create a regulatory framework that aligns immigration with the needs of the construction sector. This approach facilitates macroeconomic stabilization by avoiding sudden variations in the cost of labour.

6.2. Study Limitations

The main limitation of this research's generalization is that the Lisbon Metropolitan Area cannot be decoupled from the troubled times that resulted in the intervention of the Troika. Indeed, the metropolitan region of the Portuguese capital was subject to several shocks that disturbed the relationships among the variables used in this study.

Another shortcoming is the influence of real estate bubbles on the stability of estimated parameters for future analysis of a post-bubble burst. Consequently, the findings can be conditional on the specificities of the period where the research was done. In the same way, the Portuguese situation, where the level of indebtedness is massive, is a challenging concern because most of the debt is foreign. This situation exposes the Lisbon Metropolitan Area to outside shocks that were impossible to assess with our model. Finally, it is important to acknowledge the limitations of our investigation, particularly regarding the feasibility of conducting a comparative analysis with similar studies in other regions. The existence of a gap in the literature on the specific topic we have examined poses a significant challenge in this regard. Despite our diligent efforts to conduct an extensive literature review, we encountered limited studies that directly explore the impact of green homes on economic development in the context of Lisbon or comparable regions. This scarcity of comparable studies hinders our ability to conduct a comprehensive comparative analysis and directly benchmark our findings against similar investigations conducted elsewhere.

This limitation sheds light on this specific domain's relatively nascent research landscape. However, we emphasize that our study still holds great value as it fills an essential gap in the literature by providing a detailed analysis of the impact of green homes on economic development in the unique context of the Lisbon Metropolitan Area. We offer valuable insights and contribute to the broader understanding of sustainable urban development by examining the local socioeconomic factors, policy frameworks, and stakeholder perspectives. Although a direct comparative analysis is impossible, our findings provide a foundation for future research. They can serve as a reference for policymakers and practitioners seeking to implement sustainable practices in similar regions.

6.3. Further Research

The logical extension of this research is extending the analysis to how efficiently stimulate the huge Portuguese potential to gain from new dwellings. Indeed, building eco-friendly houses is an essential tool in limiting environmental damage in an era where there is no alternative but to implement it. Consequently, assessing how new dwellings can be accelerated is essential.

The finding that dwellings reconstruction does not impact economic growth is unexpected. Portugal has a stable population that ages quickly. Given that most residential property is traditional, there is a huge potential to gain with dwellings reconstruction if it was identified the reasons that are hampering its contributions to economic growth. In this case, Portugal can benefit from leaping several stages and taking advantage of improved construction technologies.

Another area needing research is the psychological factors' role in building eco-friendly houses. Assessing them will help cope with the vast energy transition costs and fight climate changes for contemporaneous society.

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Data Availability Statement: Data is available on request from the corresponding author.

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

Appendix A

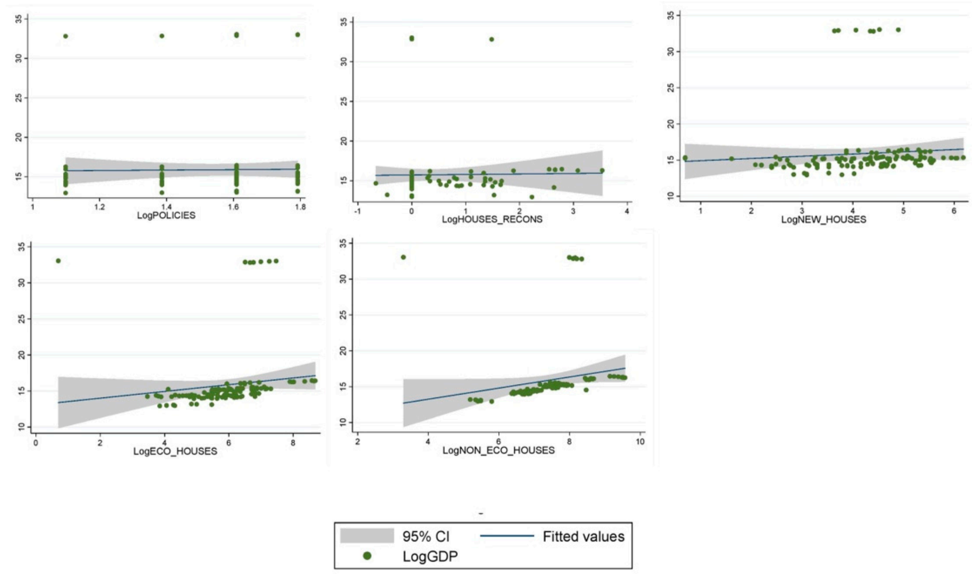

Figure A1. OLS regression with fixed effects.

Appendix B

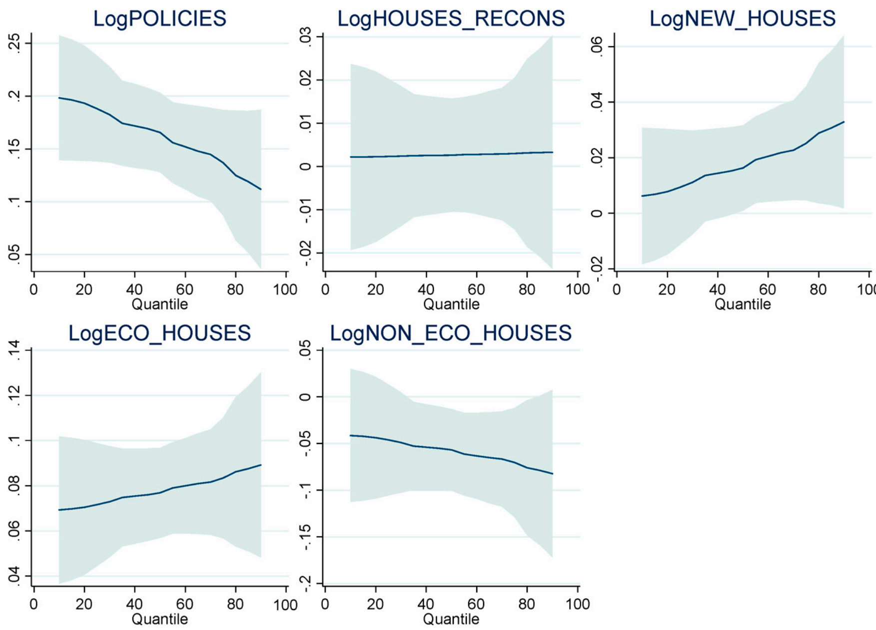

Figure A2. MM-QR regression.

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The Role of State Aid in the Achievement of the Energy Efficiency Objective in the Food Industry—The Example of Poland

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Abstract: The aims of the article are to assess the legal conditions for improving energy efficiency in the energy-intensive food industry in Poland, including the rules for financing enterprises from public funds, and to assess the extent of state aid for these enterprises in their pursuit of energy saving goals. A critical analysis of the literature and of legal regulations on energy efficiency in EU and Polish law has been performed. The analysis of state aid is based on SUDOP data, and it takes into account the time span, the food industry structure, the enterprise size, the type and purpose of aid granted, and the degree of aid concentration. The conducted research showed that the largest share of state aid is received by energy-intensive industries, i.e., meat, fruit and vegetables, and dairy products (65.5%), and by large- and medium-sized enterprises (82.4%). This aid was allocated through various programmes and in various forms, the most important of which were subsidies. The aid focused on three objectives, i.e., promotion of energy from renewable sources, high-efficiency cogeneration, and measures supporting energy efficiency. The study shows the development of legislation on energy efficiency and possibilities for financing investments, both at the EU and national levels. Tightening climate policy will enhance the importance of energy efficiency in the food industry, which should be reflected in an increase in the relatively low current level of this aid (amounting to 0.04% of total state aid and 0.17% of aid for environmental protection and energy purposes).

Keywords: energy efficiency; state aid; food industry; public policies; policy instruments; legal and regulatory framework

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1. Introduction

The world's food systems currently face significant challenges, not only in terms of production or nutritional goals but also in terms of environmental impacts, including energy use [1–3]. The modern agri-food system involves a wide range of energy users, starting with farmers, from processing, packaging, transport, retail, and households to waste disposal [4]. Energy is required in the processes related to the production, processing, distribution, consumption, and disposal of food [5]. It is also important for the sustainability of agriculture and food systems, rural development, renewable energy, and the depleting natural resources of fossil fuels [6]. Demand for energy is increasing, and this is also the case in the food system, which is partly due to the increase in global food production stemming from growing consumption [7–9]. Although fossil fuels meet most of the primary energy needs of the food system, there is a growing need for renewable energy [10]. This energy transition is also important in the context of climate change and the war in Ukraine, resulting in high prices and risk of energy supplies [11,12].

According to the FAO, the challenges for energy-smart agri-food systems (ESAFSs) include improving energy efficiency, i.e., the ratio of outputs to energy inputs all along the agri-food chain, using a variety of energy sources, with a focus on renewable energy and contributing to renewable energy production [13]. The principle of "energy efficiency" (i.e., using energy more efficiently at all stages of the energy chain, from production to final consumption), is one of the key European Union (EU) regulations and should be taken into account in all sectors [14]. Improving energy efficiency, including in the food industry, means increasing it, e.g., through technological changes such as cogeneration, i.e., the simultaneous generation of heat and electricity or mechanical energy in the same process (combined heat and power—CHP) [15,16]. Energy efficiency is recognised as a significant factor in achieving various societal goals related to environmental and climate protection, competitiveness, and energy security. Its main advantage is its potential to reduce both the economic and environmental costs and negative environmental side effects associated with the transition to low-carbon energy systems [17–19].

This principle should be applied in conjunction with and in accordance with other policy objectives of the EU. Even if other policy objectives are considered overriding, this principle should not be automatically rejected [20–22]. The new Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency [23] states that increasing the EU's energy-efficiency target can lead to lower energy prices and can also have a decisive impact on reducing greenhouse gas emissions (a reduction in these gas emissions of at least 55% below 1990 levels is to be achieved in the coming years). Such measures will have a positive influence on the environment and the living conditions of the population [24].

The development of production in the food industry, modernisation of production processes, increases in the profitability and competitiveness of plants, and adaptation to the challenges of the fourth industrial revolution can all be achieved thanks to investments in fixed assets [25]. Improving the energy efficiency of industry is achievable thanks to investments [26]. Such investments often entail a financial challenge for the food industry, as it is characterised by its relatively low average profitability, although this varies in individual industries in Poland [27,28]. Improving energy efficiency therefore requires state support [29]. State aid can only be granted if the legal requirements are met. These regulations, such as those concerning the implementation of renewable energy sources in the agri-food sector, have an impact on the development of ESAFSs [30]. The implementation of investments with the participation of state aid is usually indispensable for companies that contribute to the process of increasing energy efficiency.

The EU and Polish national legislation on the granting of state aid through public funds, EU competition rules, horizontal aid rules, and energy efficiency is extensive, complicated, and difficult to put into practice. There is a lack of research showing a detailed analysis of public aid aimed at goals related to the current problem of energy saving in such an important part of the economy in Poland as the food industry. Consequently, only a combined legal and economic approach allows for the issue to be presented fully and in an interdisciplinary manner.

Therefore, the first aim of this article is to assess the legal conditions for improving energy efficiency in the Polish food industry, in particular, the rules for financing projects from public funds. The second aim is to assess the extent of state aid for enterprises in all sectors of the food industry in their pursuit of energy saving goals. The paper attempts to answer several research questions:

1. What is the legal scope of the concept of energy efficiency? Does energy efficiency affect environmental protection and the struggle to combat climate change? If so, how? Is efficiency a challenge for EU policies? What are the links between a just energy transition and efficiency?
2. Do EU state aid and competitiveness rules allow for derogations from the general rule of Article 107 of the Treaty on the Functioning of the European Union [31] in the field of energy-efficiency investments, including in particular renewable energy, and if so, to what extent?
3. To what extent are efficiency rules being developed in EU and Polish legislation?

4. What is the scope of state aid for energy-efficiency purposes in the energy-intensive food industry in Poland?
5. Does aid for enterprises vary depending on the type of food industry, size of enterprises, aid programme, form of aid, or its purpose?

The responses to questions 1–3 related to the first aim will be presented in the part analysing legal acts in Section 2. Answers to questions 4–5 related to the second aim will be provided through empirical analysis in Section 4.

2. Legal Regulations and Literature Review

2.1. Energy Consumption in the Food Industry

Energy consumption in food processing and food distribution accounts for some 40% of that in the entire food system and is slightly higher in high-GDP countries and lower in low-GDP countries [13]. Indeed, according to research conducted in the US, energy consumption in the processing industry, e.g., for cooking, cooling, or freezing processes, averages some 14–20% of the total energy consumption in the food system [32–34]. In some of the branches of the food industry, we can find over forty energy-intensive processes [35]. Energy consumption in agri-food processing plants depends, among other things, on the thermophysical properties of raw materials, volume and structure of production, plant technical equipment, production technology, degree of mechanisation of production operations, organisation of production, and level of utilisation of processing capacity [36].

Research indicates that increased energy consumption in slaughterhouses results from an expansion in the use of automated equipment, temperature control, and hot cleaning water, as well as freezing, slicing, and boning processes [37,38]. The fruit and vegetable processing and preservation industries also consume substantial amounts of energy due to such aspects as drying processes for fruits and vegetables that contain large amounts of water [39] and the energy-intensive freeze-drying process, which allows processors to maintain the high quality of the raw material, especially that with a short shelf life, such as soft fruits [40]. The drying process requires a lot of energy; hence, it frequently involves devices used to reduce non-renewable energy consumption, e.g., solar dryers [41,42]. Milk manufacturing involves energy-intensive thermal processes such as pasteurisation [43] and heat treatments that are important for the safe consumption of milk compounds, including proteins and their antioxidant properties [44]. The largest consumers in Poland's food and beverage production sector are meat and milk processing (20% in 2022), and at the same time, these industries have the largest share in sold production in this industry (24%); therefore, the energy intensity of sold production is low [45,46].

Food industry enterprises occupy an important position in the EU economy, as in 2022, their sales revenues amounted to EUR 1.5 trillion, i.e., as much as 59% more than in 2010. Poland ranks seventh in terms of the value of revenues (EUR 96.6 billion) and demonstrated a dynamic growth by 114%. In Poland, the food industry generates almost one-fifth of the total value of sold industrial products [47], and the growing domestic production in most plant and animal products covers domestic consumption, ensuring food self-sufficiency for the inhabitants of Poland [48] and also Europe. This is because surpluses in production are exported, mostly to other EU members, and the balance of foreign trade in agri-food products is both positive and constantly growing [49]. Such a situation has global relevance, the reason being that if Europe loses its food self-sufficiency, this situation might aggravate ecological problems in other parts of the world if an additional amount of food, understood as an energy resource, had to be produced in areas that are valuable from the point of view of environmental protection [50].

Between 2010 and 2022, energy consumption in the food, beverage, and tobacco industry increased in most of the EU's 28 Member States (Figure 1), with a rise of 27% in Poland. Poland belongs to the group of countries with significant energy consumption in this sector (94.5 PJ in 2022). A positive phenomenon is the growing share of renewables and biofuels in energy consumption in the food industry in the EU, which rose from 3.4% to 4.7% between 2010 and 2022 and from 0.7% to 1.7% in Poland, thanks to an almost threefold increase in volume to 1.6 PJ. The share of combined heat and power (CHP) in energy consumption in the EU food industry surged from 4.9% to 5.7%. In Poland, however, despite the expansion in the level of cogeneration by 88% to 2.6 PJ, its share in energy consumption in this industry increased only by one percentage point to 2.8% [51]. The food industry in Poland, just like the entire economy, is undergoing modernisation changes in the energy economy [52,53]. Despite the growing demand for electricity in the food industry, which results from, among others, investments in fixed capital and the automation and digitisation of production technologies, the energy intensity of sold production in the industry and most of its branches is decreasing, which indicates an improvement in energy efficiency. This is important in the context of cost competitiveness and meeting growing environmental protection requirements [52].

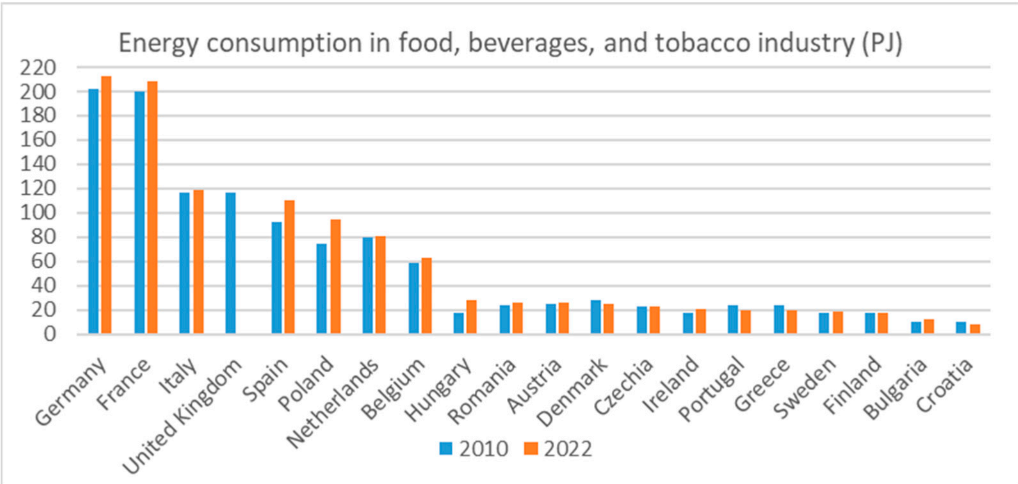

Figure 1. Energy consumption in the food, beverage, and tobacco industry in the EU countries, where the values are over 10 PJ. Source: own work based on [51].

The rise in energy consumption in the food industry is influenced by such factors as the growing total consumer demand for food, including energy-intensive food, for example, highly processed goods, fresh processed food, and ready-to-eat food. These types of food require energy-intensive production technologies or more energy to avoid spoilage on the way from the field to the table [32,54]. The overall growth in energy consumption in the EU is due to the rise in the level of production of the food industry generated, among others, by the increase in the number of entities operating in the industry. Between 2010 and 2022, in EU-28, the number of food industry enterprises expanded by over 25,000 to 316,000, of which 88% were engaged in the production of food products and 12% in the production of beverages. Poland accounted for almost one-fifth of the new entities. In Poland, in 2022, there were 19,100 enterprises from this sector (of which 96% produced food products), ranking it fifth in the EU [55].

Financial support for investments is crucial to accelerate the transition to a low-carbon economy [56]. The implementation of some renewable energy solutions is still associated with high initial costs, e.g., the cost of the technologies themselves, which is why state support with various instruments proves crucial [53,57]. The support policy implemented in this respect should be targeted, flexible, and adapted to local needs and should take into account innovation in order for entities to use products with higher added value in the field of renewable energies [58–61]. State investment support increases profitability and competitiveness and promotes efficient resource management of supported food industry enterprises [62].

State aid for environmental protection and energy in Poland is increasing (by 148% to EUR 1.9 billion in 2016–2022) [63,64], but comparing its amount to that of other countries in the EU, it is a low value [65,66]. Research on state aid for environmental protection and energy in the selected branches of the food industry in Poland indicates its low level and low share (7.6%) of total aid for the dairy industry [67]. There is a lack of research that would indicate the level of state aid in the food industry in Poland and all its branches directed specifically to the goal related to energy efficiency. There are no studies indicating forms of aid or specific goals in this area. We will try to analyse the scope of this aid also in the context of applicable legal acts at the national and EU level.

The development of the food industry is influenced by micro- and macroeconomic conditions. The first ones include the enterprise management system, organisational and ownership structure of the enterprise, sources of financing, level of investment, technology, and innovation. The second group includes the economic situation in the country; the implemented fiscal, monetary, investment, and credit policies; foreign policy supporting exports; new food consumption patterns; and the state's legislative policy [68]. The rest of this section will be devoted to the analysis of legal acts affecting energy efficiency in the Polish food industry.

2.2. Improving Energy Efficiency in the Context of EU Policies

A fair transition towards achieving the Union's climate neutrality by 2050 is crucial for the implementation of the European Green Deal [69], European Union policies, democracy, and equality [70]. Article 194 of the Treaty on the Functioning of the European Union [31] states that within the framework for the establishment or functioning of the internal market, and with regard to the need to preserve and improve the environment, Union policy on energy shall aim, firstly, in the spirit of solidarity between Member States; secondly, to ensure that the energy market functions; thirdly, to ensure security of the energy supply in the Union; and fourthly, to promote energy efficiency and energy saving and to develop new and renewable forms of energy [71]. It should be emphasised that the energy sector is a shared competence, which means that the EU has the primary competence to legislate in the energy sector. The Member States, on the other hand, can only exercise their competence to the extent that the EU has not done so [71].

For many years, the EU has focused on implementing a climate and energy policy framework. Energy strategy is therefore linked to EU environmental policy and also to the agri-food industry, regional development, and transport. It should be noted that there has been an interest in energy efficiency in the EU for many years. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency has been implemented by Member States [15], for example, in Portuguese Decree-Law No. 68-A/2015—Diario da Regublica No. 84/2015, Supplement 1st, Series I, 30 April 2015 Ministry of Environment, Spatial Planning and Energy, which establishes regulations on energy efficiency and cogeneration production, transposing Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency [72]. Other examples are the Dutch Act on Implementation of EU Directives on Energy Efficiency and the Dutch Act of 28 February 2015 amending the Act on Implementation of EU Directives on Energy Efficiency, the Electricity Act 1998, the Gas Act, and the Heat Act in connection with the implementation of Directive 2012/27/EU on energy efficiency [73].

Member States should be encouraged to make full use of the Structural and Cohesion Funds to stimulate investment in energy-efficiency measures. On the other hand, banks and other financial institutions should be actively involved in providing information on how they can participate in the financing of energy-efficiency measures, including through the creation of public–private partnerships. Furthermore, Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency expands on the efficiency challenge and highlights how energy-efficiency measures have a positive impact on the environment and contribute in a cost-effective way to achieving the EU's air-quality policy objectives, in particular those set out in Directive (EU) 2016/2284 of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants [74,75].

According to Directive (EU) 2023/1791, "system efficiency" means the choice of energy-efficient solutions that also allow for a cost-effective decarbonisation pathway, additional flexibility, and efficient use of resources; on the other hand, "energy efficiency improvement" indicates an increase in energy efficiency as a result of any technological, behavioural, or economic change (Art. 2 of the Directive). Energy generated on or in buildings [76] using renewable energy technologies or agro-voltaics reduces the amount of energy supplied by fossil fuels [77], which is part of the current challenge to achieve such objectives as those of the European Green Deal (presented by the European Commission on 11 December 2019) [78]. These include the promotion of green finance and investment, more ambitious EU climate change targets; clean, affordable, and secure energy; and the development of circular economies.

As mentioned above, the development of renewable energy is important to achieve climate neutrality. According to Articles 2 and 4 of the Regulation of 30 June 2021 establishing a framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ("European Climate Law") [79], Union-wide emissions and removals of greenhouse gases regulated in Union law shall be balanced at the latest by 2050, thus reducing emissions to net zero by that date, with the Union moving towards negative emissions. The Union's binding climate change target for 2030 is a reduction of at least 55% in its net greenhouse gas emissions (emissions minus removals) by 2030 compared to 1990 levels. Efforts for developing renewable energy and improving energy efficiency also aim to implement the UN's 2030 Agenda for Sustainable Development [80] and are in line with the principles of the green economy. The latter emphasises that the economy should be low-carbon, resource-efficient, and "inclusive". There is a need to increase energy and resource efficiency and prevent the loss of biodiversity and ecosystem services [81]. Some of these actions are driven by the European Climate Change legislation, which aims to achieve zero net greenhouse gas emissions by 2050.

The communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee, and the Committee of the Regions, "Ready for 55": meeting the EU's 2030 [82] climate target on the road to climate neutrality, highlights that energy consumption accounts for 75% of emissions in the European Union. Transforming the energy system is therefore key to achieving the ambitious climate targets that have been set. Accordingly, the share of renewable energy sources in the European Union's energy mix should increase from 32% to 40%. Directive (EU) 2023/1791 recommends reducing final energy consumption by at least 11.7% in 2030 compared to energy consumption projections in 2020.

Energy efficiency is also an important issue in the EU Member States. In Germany, for example, the Energy Efficiency Act of 13 November 2023 entered into force on 18 November 2023 [83]. Some of the aims of this legislation are to increase energy efficiency, improve security of supply, and mitigate global climate change. It also seeks to ensure that national energy-efficiency targets are met and consistent with European targets. For the period after 2030, the German government aims to reduce Germany's final energy consumption by 45 per cent by 2045 compared to that in 2008. The new final energy savings are to be achieved not only through investment but also through strategic measures by the Länder. The latter should focus on information, advice, education, and promotion. section 6 on climate-neutral enterprises is of particular interest. The federal government is empowered to establish exceptions and exemptions for climate-neutral companies from the obligations under sections 11–13 and 15–17. It is emphasised that only companies that are compatible with the goal of a sustainable energy supply and the achievement of national and European climate protection goals can be considered climate neutral. Important points were highlighted regarding the requirements for declaring companies as climate neutral, the obligations to provide evidence for declaring companies as climate neutral, and the monitoring of these declarations. It is also worth mentioning that an energy audit is a systematic procedure for identifying measures to increase energy efficiency and reduce energy consumption in a company, including obtaining sufficient information on the energy consumption profile of the organisation, its buildings, and the operation of its equipment; identifying and quantifying the potential for final energy savings; and identifying the potential for the use and production of renewable energy [83]. Italy also has extensive legislation on renewable energy and energy efficiency; for example, Legislative Decree No 102 of 4 July 2014 "Implementation of Directive 2012/27/EU on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC" [84], or Law 181 of 9 December 2023, contains provisions on national energy security, the promotion of the use of renewable energy sources, support for energy-intensive enterprises, and the reconstruction of areas affected by exceptional floods [85]. Among other things, it emphasises the need to promote and accelerate investment in the self-generation of renewable energy in energy-intensive sectors.

2.3. Energy-Efficiency Legislation in Poland

The basic act on energy efficiency in Polish law is the Act of 20 May 2016 on Energy Efficiency [86]. According to these regulations, an energy-efficiency improvement project is an action that consists of introducing changes or improvements to a building, technical device, or installation, resulting in energy savings [87,88]. Examples include insulating industrial facilities; energy generation in renewable energy facilities; reconstruction or renovation of a building together with its facilities and technical equipment; energy recovery, including energy recovery in industrial processes; reducing losses, e.g., those related to reactive energy consumption and network losses related to the transmission or distribution of electricity, natural gas, or liquid fuels. As a rule, such projects are extremely expensive [89]. The source of funding is therefore very important, and this includes EU grants, soft loans, or financing. In principle, public support is complicated by Article 107 of the Treaty on the Functioning of the European Union. This states that any aid granted by a Member State or through State resources in any form whatsoever which distorts or threatens to distort competition by favouring certain undertakings or the production of certain goods is, in so far as it affects trade between Member States, incompatible with the common market. At the same time, it should be noted that public aid is permitted, for example, in the form of horizontal or regional aid [90].

The legislation provides a number of instruments to improve efficiency and assess the current situation. An entrepreneur within the meaning of the Act of 6 March 2018 on Entrepreneurs Law [91], with the exception of micro-, small, or medium-sized businesses, shall carry out or have carried out an energy audit of the enterprise every 4 years. This must be conducted by an entity independent of the audited entrepreneur, with knowledge and professional experience in carrying out this type of audit or an expert of the audited entrepreneur, if he is not directly involved in the audited activity of this enterprise. Energy efficiency is not only important for large companies. It is also significant for all businesses because it allows the current energy situation to be assessed and action to be taken to reduce energy consumption. Lower energy costs and a positive impact on the environment are evident [92]. In practice, this also indicates a need to increase energy security, raise productivity, boost innovation and competitiveness, meet legal requirements and standards, build an image of a pro-environmental company, reduce greenhouse gas emissions, decrease pollutant emissions, promote social benefits, and increase occupational safety.

It is worth referring to the concept of energy efficiency, which, in the context of the Act under discussion, is the ratio of the achieved magnitude of the useful effect of a given object, technical device, or installation, under typical conditions of its use or operation, to the amount of energy consumed by this object, technical device, or installation or as a result of the performed service necessary to achieve this effect. According to the announcement from the Minister of Climate and Environment of 30 November 2021 on a detailed list of energy-efficiency improvement projects [93], such investments include those related to the insulation of industrial installations; the reconstruction or renovation of a building together with technical installations and equipment, including thermo-modernisation and renovation projects; the modernisation or replacement of equipment and installations used in industrial, telecommunications, or IT processes and in energy processes; own-use equipment and installations used in energy processes carried out in fuel combustion installations covered by the Emissions Trading Scheme; the construction of a connection to a district heating network; and the purchase or modernisation of a heat distribution centre in order to replace heat from heat sources with low energy efficiency with heat from a district heating network generated by an installation using renewable energy sources in a high-efficiency cogeneration plant or in the form of waste heat from industrial installations. There is no doubt that the scope is wide, and individual entrepreneurs can make investment choices taking into account their own situations. At the same time, it should be emphasised that the Energy Efficiency Act has to be amended due to the new challenges such as social development and climate change.

The announcement of the Polish Minister of Climate and Environment of 2 March 2021 on the State Energy Policy until 2040 states the following [94]: "Renewable energy sources will play an increasingly important role—their share in the structure of the net national electricity consumption will not be less than 32% in 2030, which will primarily enable the development of photovoltaics and offshore wind farms, which enjoy the greatest development prospects due to economic and technical conditions. The development of grid infrastructure and energy storage technologies is necessary to achieve this level of renewable energy in the balance". The amended Act of 20 February 2015 on Renewable Energy Sources [95] creates new opportunities for the development of renewable energy in Poland. It is also worth mentioning cogeneration, which is defined in Article 3(33) of the Act of 10 April 1997 on energy [96] as the simultaneous production of heat and electricity or mechanical energy during the same technological process [97,98], e.g., gas cogeneration [99]. To be called high-efficiency, savings of a certain order must be achieved in this process [100]. As can be seen from the literature, the aforementioned methods of energy production are conducive to improving energy efficiency. This allows for the production of two different types of energy while conserving raw materials from a single source [101]. Cogeneration also contributes to the reduction in greenhouse gas emissions and other pollutants by decreasing the amount of fuel used for the combined production of heat and electricity [102]. The Act of 14 December 2018 on the promotion of electricity from high-efficiency cogeneration [103] sets out the rules for providing support for electricity generated in high-efficiency cogeneration units and for issuing guarantees of origin for electricity from high-efficiency cogeneration.

It is also worth mentioning a legal instrument that also encourages entrepreneurs in the agri-food industry to make investments leading to greater energy efficiency, namely energy efficiency certificates ("white certificates"). These confirm that the planned investments will lead to a reduction in the amount of final energy and serve to improve energy efficiency. It is important to note that in accordance with the Polish Energy Efficiency Act of 20 May 2016, such a certificate is not entitled to a project or projects of the same type for improving energy efficiency if the granting of this certificate will result in a permissible amount of public aid for this project or these projects stipulated in the Act being exceeded (Art. 20–32 of the Polish Energy Efficiency Act). The certificate is issued by the President of the Energy Regulatory Office at the request of the entity planning to commence the implementation of one or more projects of the same type aimed at improving energy efficiency. The property rights resulting from the energy efficiency certificate are a commodity in the sense of the Commodity Exchange Act of 26 October 2000 [92,104].

A summary of the legal acts discussed so far is provided in Table 1.

2.4. Public Support Instruments for Energy Efficiency in the Food Industry

According to the concept of state aid in the Treaty on the Functioning of the European Union, the implementation of an energy-efficiency pre-project requires significant financial resources, which are very often public funds. According to Art. 9 of the Polish Act of 27 August 2009 on Public Finance [105], public funds are public revenues, funds from the budget of the European Union, and non-refundable funds from aid granted by member states of the European Free Trade Agreement (EFTA); revenues of the state budget and budgets of local government units and other units of the public finance sector, which result from factors such as repayments of loans granted from public funds and from loans and credits received; and the revenues of public sector bodies resulting from their activities and from other sources.

Table 1. Selected energy-efficiency regulations.

EU Regulations on Energy Efficiency	Example Regulations of Selected EU Countries Implementing the Directive	Polish Regulations on Efficiency
Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC [15]	Italian Legislative Decree No 102 of 4 July 2014 "Implementation of Directive 2012/27/EU" [84]	Announcement by the Minister of Climate and Environment of 30 November 2021 on a detailed list of energy-efficiency improvement projects [93]
Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency [23]	Dutch Act on Implementation of EU Directives on Energy Efficiency [73]	Act of 20 May 2016 on Energy Efficiency [86]
	German Energy Efficiency Act of 13 November 2023 [83]	
	Portuguese Decree-Law No. 68–A/2015—Diario da Regublica No. 84/2015 [72]	

Source: own work based on [15,23,72,73,83,84,86,93].

There is no definition of state aid in Polish legislation. In the everyday meaning, it is broadly understood to include all public funds granted from state resources by national, regional, or local authorities, as well as banks, foundations using public funds, etc. [106]. This includes, in particular, public funds as defined in the Public Finance Act. The concept of state aid has a narrower meaning when used in EU legislation. On the basis of the Treaty on the Functioning of the European Union, state aid can be considered prohibited support granted to an enterprise if the following conditions are simultaneously met: first, it is granted by the state or comes from state resources; second, it is granted on terms more favourable than those offered on the market; third, it is selective (favours a particular undertaking or undertakings or the production of particular goods); and fourth, it threatens to distort or does distort competition and affects trade between EU Member States. Thus, for support to constitute state aid, the above conditions must be cumulative [107]. According to the Commission's July 2016 Notice on the concept of state aid as referred to in Article 107(1) of the Treaty on the Functioning of the European Union (2016/C 262/01), an advantage within the meaning of Article 107(1) of the Treaty means any economic advantage that the concerned undertaking could not obtain under normal market conditions, i.e., without state intervention. If one of the above conditions is not met, there is no state aid under the EC Treaty or, referring to the nomenclature used in the literature, the state aid in question is not anti-competitive [90,108].

Aid measures fulfilling the above criteria are in principle incompatible with the common market under Article 107(1) of the EC Treaty. At the same time, it should be noted that this does not mean that such aid is prohibited altogether. Aid may be considered compatible with the common market if, for example, it is intended to promote the economic development of areas where the standard of living is abnormally low or where there is serious underemployment, or of regions with structural, economic, and social difficulties. Public aid may also be authorised to promote the execution of an important project of common European interest; to remedy a serious disturbance in the economy of a Member State; or to facilitate the development of certain economic activities or of certain economic areas, where such aid does not adversely affect trading conditions to an extent contrary to the common interest. Such aid may be authorised, and the Council may determine this by a decision on a proposal from the Commission. Article 108 of the Treaty on the Functioning of the European Union provides that, at the request of a Member State, the Council, acting unanimously, may decide that aid which that State is granting or intends to grant shall be considered compatible with the internal market by way of derogation from the provisions of Article 107 or from the regulations provided for in Article 109. It should be underlined that such a decision may be taken if justified by exceptional circumstances. The Council, acting on a proposal from the Commission and after consulting the European Parliament, may adopt regulations for the application of Articles 107 and 108 and, in particular, may determine the conditions for the application of Article 108(3) and the categories of aid exempted from this procedure (Article 109 of the Treaty). Examples of acts adopted by the Council on the basis of Article 109 are Regulation (EC) No 659/1999 laying down detailed rules for the application of Article 88 of the EC Treaty and, on this basis, the Commission's implementation of Regulation (EC) No 794/2004 [109], as well as Council Regulation (EC) No 994/98 of 7 May 1998 on the application of Articles 107 and 108 of the Treaty on the Functioning of the European Union to certain categories of horizontal state aid [110,111].

The above-mentioned Regulation No 994/98 of 7 May 1998 stipulates that the Commission may (by means of a regulation adopted in accordance with the procedure laid down in Article 8 of the Regulation), declare, in accordance with Article 92 of the Treaty, that certain categories of aid are compatible with the common market and are not subject to the notification requirement of Article 93(3) of the Treaty, namely, aid for small and medium-sized enterprises; for research, development, and innovation; for the protection of the environment; for the promotion of food products not listed in Annex I to the TFEU; for employment and training; for repairing damage caused by natural disasters; for repairing damage caused by certain adverse weather conditions in the fisheries sector; and for forestry. This regulation was subsequently repealed by Council Regulation (EU) 2015/1588 of 13 July 2015 on the application of Articles 107 and 108 of the Treaty on the Functioning of the European Union to certain categories of horizontal state aid [112]. This provides for the financing of renewable energy and other environmental and energy-efficiency investments [89]. Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency Article 30 states that, without prejudice to Articles 107 and 108 TFEU, Member States shall facilitate the creation of financial instruments or the use of existing instruments for measures aimed at improving energy efficiency. The main objective is to maximise the benefits of funding from different sources and the use of a combination of grants, financial instruments, and technical assistance. Member States may establish a national energy-efficiency fund whose purpose is to implement energy-efficiency measures to support Member States in the implementation of their national energy-efficiency contributions. It may be created as a dedicated fund within an existing national investment support facility. It could be financed by revenues from the auctioning of allowances under the EU Emissions Trading Scheme. It is important to increase the uptake of private investment in energy efficiency and innovative schemes.

2.5. Horizontal State Aid for Environmental Protection

Council Regulation (EU) 2015/1588 of 13 July 2015 on the application of Articles 107 and 108 of the TFEU to certain categories of horizontal state aid [112] provides that the Commission may declare that certain categories of aid are compatible with the internal market and are not subject to the notification requirement of Article 108(3) TFEU. Such aid includes aid for environmental protection. On the basis of Article 107(3)(c) of the Treaty, the Commission may declare state aid that facilitates the development of certain economic activities in the European Union to be compatible with the internal market, where such aid does not adversely affect trading conditions to an extent contrary to the common interest. For example, this includes the guidelines on state aid for environmental and energy-related objectives 2014–2020 applied to state aid granted for environmental or energy-related objectives in all sectors subject to the provisions of the Treaty, to the extent that such measures are covered by point 1.2 in the guidelines. The general objective of aid under the environmental guidelines is to raise the level of environmental protection compared to the level that would have been achieved without aid [113]. In particular, the Europe 2020 strategy sets targets for sustainable economic growth that would support the transition to a resource-efficient, competitive, low-carbon economy. A low-carbon economy with a significant share of variable energy production from renewable sources requires adaptation of the energy system and, in particular, significant investment in energy networks (37). The main objective of state aid in the energy sector is to ensure a competitive, sustainable, and secure energy system in a well-functioning EU energy market (38). The Commission has identified a number of environmental and energy-related measures for which, under certain conditions, state aid may be compatible with the internal market on the basis of Article 107(3)(c) of the Treaty on the Functioning of the European Union. For example, this includes aid for the production of energy from renewable sources; aid for energy-efficiency measures, including cogeneration and district heating and cooling; aid for CO_2 capture, transport, and storage, including individual elements of the carbon capture and storage (CCS) chain; aid in the form of reductions in or exemptions from environmental taxes; and aid in the form of reductions in the financing of support for renewable electricity. It was emphasised that aid for environmental protection and energy-related objectives cannot be granted to undertakings in a difficult situation, as defined for the purposes of these guidelines in the applicable guidelines on state aid for rescuing and restructuring firms in difficulty (19). It was pointed out that energy-efficiency measures are undertaken in relation to negative externalities, creating individual incentives to achieve environmental objectives in terms of energy efficiency and reductions in greenhouse gas emission.

In terms of state aid earmarked, for example, for energy efficiency, reference should be made to the Regulation of the Polish Minister of the Environment of 21 December 2015 on the detailed conditions for granting horizontal public aid for environmental protection purposes [114]. This legal act sets out the detailed conditions for granting horizontal public aid for environmental protection purposes from the funds at the disposal of the Polish National Fund for Environmental Protection and Water Management and the provincial funds for environmental protection and water management. This executive act was issued on the basis of Article 400a(2) of the Act of 27 April 2001—the Environmental Protection Law [115]. The financing of environmental protection and water management includes support for the use of local renewable energy sources and the introduction of more environmentally friendly energy carriers or other environmental protection and water management tasks resulting from the principle of sustainable development and consistent with environmental policy. The horizontal aid scheme for environmental protection is based on Commission Regulation (EU) No 651/2014 of 17 June 2014, declaring certain categories of aid compatible with the internal market [107,116]. According to the Polish Ordinance of the Minister of the Environment of 21 December 2015, aid may be granted for investments enabling increases in energy efficiency, as referred to in Art. 2(103) of Commission Regulation (EU) No. 651/2014; investments serving to generate energy in high-efficiency cogeneration, as referred to in Art. 2(107) of Commission Regulation (EU) No 651/2014; investments for the production of energy from renewable energy sources, as referred to in Article 2(110) of Commission Regulation (EU) No 651/2014 or investments for the production of sustainable biofuels; investments in energy-efficient heating and cooling; and investments in energy infrastructure. Aid could also be granted in the form of grants, including interest subsidies on bank loans or interest-bearing loans, or as partial write-offs of interest-bearing loans. The granting of aid would have been subject to the submission of an application before the investment or environmental studies had been started. The application contains information referred to in Commission Regulation (EU) No 651/2014, as well as other information indicated by the body granting the aid and necessary for the assessment of the application.

Also of interest are the data contained in the final reports of the evaluation study entitled "Assessment of the impact of the ROP WP 2014–2020 on energy efficiency and emissions in the individual voivodships" [117]. In these documents, an evaluation was conducted of the actual and potential impact of the support offered under the individual measures of OP III of the ROP WP 2014–2020 on the volume of energy consumption and the resulting emission of pollutants. The study was divided into three research areas, renewable energy sources (RES), energy modernisation of buildings and air quality, and emission reduction, and used both quantitative and qualitative research methods. The European Commission's Guidelines on state aid for climate and environmental protection and energy 2022, 2022/C 80/0 [118] indicate that the Commission has identified a number of categories of environmental and energy-related measures for which state aid may, under certain conditions, be compatible with the internal market on the basis of Article 107(3)(c) of the EC Treaty, e.g., aid for reducing and eliminating greenhouse gas emissions, including through the promotion of renewable energy and energy efficiency; aid for the improvement of the energy and environmental performance of buildings; aid for resource efficiency and to promote the transition to a closed economy; aid for the prevention of or reduction in pollution other than greenhouse gases; aid for the security of electricity supply; aid for energy infrastructure; aid for heating and cooling systems; and aid for studies or consultancy services related to climate, environmental, and energy objectives. The Ordinance of the Minister of Funds and Regional Policy of 11 December 2022 on granting aid for investments in high-efficiency cogeneration systems and for the promotion of energy from renewable sources within the framework of regional programmes for 2021–2027 [119] specifies the purpose, conditions, and procedure for granting the following types of aid to entrepreneurs within the framework of regional programmes for 2021–2027: (1) aid for investments in high-efficiency cogeneration systems, (2) investment aid for the promotion of energy from renewable sources, and (3) aid for environmental studies. Renewable energy investments can also be financed under the Rural Development Plan. Some of the beneficiaries, such as agricultural production cooperatives, are also involved in food processing and distribution [120]. Some actors in the food industry are also involved in energy cooperatives [121]. The latter are found in many countries around the world and may benefit from government support [122,123].

It is also worth mentioning the National Plan for Reconstruction and Increasing Resilience in Poland (KPO), which is compatible with Regulation (EU) 2021/241 of the European Parliament and of the Council of 12 February 2021 establishing the Recovery and Resilience Facility [124]. Its aim is to bolster the development potential of the economy and to support the sustainable competitiveness of the economy. The objective is also to support energy efficiency, facilitate energy companies' efforts to meet their energy saving obligations, and improve conditions for the development of hydrogen and other decarbonised gas technologies. For improving conditions for the development of renewable energy sources [125], the Regulation of the Minister of State Assets of 15 November 2023 on granting public aid for investments supporting energy efficiency and renewable energy sources in enterprises within the framework of the National Plan for Reconstruction and Increasing Resilience was established [126]. This ordinance specifies the detailed purpose, conditions, and procedure for granting entrepreneurs public aid constituting investment aid: (1) enabling the improvement of energy efficiency other than in buildings, (2) enabling the achievement of energy efficiency in buildings, (3) promoting energy from renewable energy sources, and (4) promoting renewable hydrogen and high-efficiency cogeneration—from the funds of the Instrument for Reconstruction and Increasing Resilience under investment B1.2.1 "Energy efficiency and RES in enterprises—investments with the highest potential for greenhouse gas reduction", covered by the National Plan for Reconstruction and Increasing Resilience, hereinafter referred to as "aid". This aid is granted under the rules set out in Commission Regulation (EU) No. 651/2014 of 17 June 2014 declaring certain types of aid compatible with the internal market in the application of Articles 107 and 108 of the Treaty. It is dedicated to large entrepreneurs in order to reduce both final energy consumption and greenhouse gas emissions by increasing the energy efficiency of industrial and manufacturing processes of enterprises, fostering the decarbonisation of industrial enterprises, and increasing the share of low-carbon sources for energy generation in enterprises through investments in renewable energy sources and low-carbon and efficient use of the energy generated [127]. Horizontal public aid for environmental protection purposes from funds at the disposal of the provincial funds for environmental protection and water management is granted in accordance with Commission Regulation (EU) No 651/2014 of 17 June 2014, for example, declaring certain types of aid to be compatible with the internal market in the application of Articles 107 and 108 of the Treaty. Examples are investments promoting energy efficiency other than in buildings; investments promoting energy efficiency in buildings; actions facilitating energy performance contracts; investments promoting renewable energy and promoting renewable hydrogen; investments in high-efficiency cogeneration; and investments in energy-efficient district heating and cooling. Aid may be provided in the form of grants, loans, or partial loan waivers.

A summary of the legal acts on financial support from public funds is provided in Table 2.

Table 2. Selected legal regulations on financial support from public funds.

EU Regulations and Guidelines on State Aid and Aid Allowed	Polish Regulations on Financial Support for Energy-Efficiency Investments
Articles 107, 108, and 109 of the Treaty on the Functioning of the European Union [31]	Polish Act of 27 August 2009 on Public Finance [105]
Commission Regulation (EU) No 651/2014 of 17 June 2014 declaring certain categories of aid compatible with the internal market [116]	Regulation of the Polish Minister of the Environment of 21 December 2015 on the detailed conditions for granting horizontal public aid for environmental protection purposes [114]
Council Regulation (EU) 2015/1588 of 13 July 2015 on the application of Articles 107 and 108 of the Treaty on the functioning of the European Union to certain categories of horizontal State aid [112]	The Ordinance of the Minister of Funds and Regional Policy of 11 December 2022 on granting aid for investments in high-efficiency cogeneration systems and for the promotion of energy from renewable sources within the framework of regional programmes for 2021–2027 [119]
Guidelines on State aid for climate, environmental protection, and energy 2022 (2022/C 80/01) [118]	Regulation of the Minister of State Assets of 15 November 2023 on granting public aid for investments supporting energy efficiency and renewable energy sources in enterprises within the framework of the National Plan for Reconstruction and Increasing Resilience [126]
Regulation (EU) 2021/241 of the European Parliament and of the Council of 12 February 2021 establishing the Recovery and Resilience Facility [124]	Announcement of the Minister of Climate and Environment of 23 November 2023 on the list of programmes and financial instruments concerning end-user energy-efficiency improvement projects [128]
	Regulations concerning the financing of the Common Agriculture Policy EU [129,130]

Source: own work based on [31,105,112,114,116,118,119,124,126,128–130].

3. Materials and Methods

The study employs a critical analysis of the literature and legal regulations on energy efficiency in the laws of EU and Poland. We discuss the state support instruments in the implementation of the energy-efficiency target in the food industry, as well as the horizontal state support tools for environmental protection. In the theoretical part of the work, the methods of descriptive, comparative, deductive, and synthetic analysis were applied. Data from the Public Aid Data Sharing System (SUDOP) database [131] were used to conduct empirical research. The information, made available via the SUDOP system, originates from aid reports prepared via the SHRIPM (System of Scheduling, Registration and Monitoring of Public Aid—as used to monitor public aid) IT application. These are reports prepared by entities providing support on the basis of the Act of 2004 on proceedings in state aid cases [132]. Such reports shall provide information on the beneficiaries of the support and on the types, forms, amount, and purpose of the aid granted.

The SUDOP database contains no information on support measures that expired before 2016. The period of analysis for the purpose of the present article begins in 2016 and ends in 2023. The article does not include de minimis aid because that is a specific type of aid that does not meet all the criteria for state support declared incompatible with the common market [133]. Data were collected for food industry enterprises (NACE Rev. 2 Division 10 Group 10.1–10.9 and Division 11 Group 11.0). The study also uses secondary statistical data on the food industry, including its structure, effects of operation, and energy consumption from the statistical yearbooks of the Central Statistical Office in Poland (GUS) and Eurostat, as well as the level of state aid from reports of the Polish Office of Competition and Consumer Protection (UOKiK), whose president, in accordance with the Act, is the body monitoring state aid in Poland. We applied quantitative methods for the practical part of our research. The results of the analysis were based on the authors' own calculations. The analysis of state financial support takes into account the time range, the structure of the food industry, the size of enterprises, the types of aid granted, and the purpose of the aid granted. The degree of concentration of the aid provided was also calculated by means of frequency distribution. To determine whether there is a statistical relationship between the value of state aid and other variables, i.e., the size of the enterprise, group of the industry, purpose of aid, and type of aid, the chi-square test of independence was used. The hypothesis H_0 was put forward that the value of aid does not depend on these subsequent factors, compared to the hypothesis H_1 that this aid depends on these subsequent factors. The calculations were performed using Excel 2016 and IBM SPSS Statistics version 29. A p-value less than $\alpha = 0.05$ was considered statistically significant.

4. Results

On 648 occasions in the years 2016–2023, public aid for energy-efficiency purposes was granted to enterprises involved in the production of food and beverages. This amounted to EUR 41.1 million (Table 3), and, throughout the period being analysed, the frequency of granting aid, the sums of this aid, and the average value of the aid all increased. However, since 2021, despite the persistently high frequency of aid grants (amounting to more than 90 times a year), the value of aid granted has dropped from EUR 11.1 million to EUR 3.4 million. This has resulted in a decrease in the average value of the aid from EUR 104,600 to EUR 30,400.

Table 3. The value of public aid for energy-efficiency purposes in food industry enterprises in Poland in 2016–2023.

Years	Frequency of Aid	Value of Aid (EUR in Thousands)					
		Sum	Average	Median	Min	Max	Vs (%)
2016	22	489.01	22.23	11.19	0.77	92.95	121.15
2017	88	5507.54	62.59	9.67	0.08	1688.70	333.12
2018	89	6679.52	75.05	9.22	0.15	3111.29	448.66
2019	48	4434.51	92.39	7.69	0.86	1282.54	254.01
2020	91	4543.58	49.93	15.04	0.14	998.65	252.34
2021	106	11,084.54	104.57	14.05	0.01	1949.04	303.04
2022	93	5001.37	53.78	7.00	0.04	779.54	241.87
2023	110	3373.24	30.39	7.52	0.08	760.48	266.18

Vs—coefficient of variation. Source: own work based on [131].

We noted a very large variation in the value of aid provided in each of the years subjected to our analysis. Therefore, for half of the aid measures, their value was much lower than the mean value of the respective year. This is particularly evident in the case of years when the difference between the extreme values was very large. In some years (2017–2019, 2021), the range was even above EUR 1 million. Indeed, throughout the period being analysed, the minimum value of aid ranged from EUR 0.01 thousand to EUR 0.86 thousand, while the maximum value ranged from EUR 0.1 million to EUR 3.1 million.

In 2023, 62 enterprises of the food industry were granted public aid. Here, the total amount was three times that in 2016 (Figure 2). In addition, the increasing subjective scope of aid was accompanied by an increase in the mean value of aid granted to enterprises (from EUR 22,200 to EUR 54,400). Moreover, the largest mean aid for an entity occurred in

2021 (over EUR 165,000), and, at this time, the largest number of entities also received such support (67), with a high total value of the aid granted (over EUR 11 million). Overall, in the period being analysed, the mean number of aid activities implemented for any entity increased from 1 to almost 2.

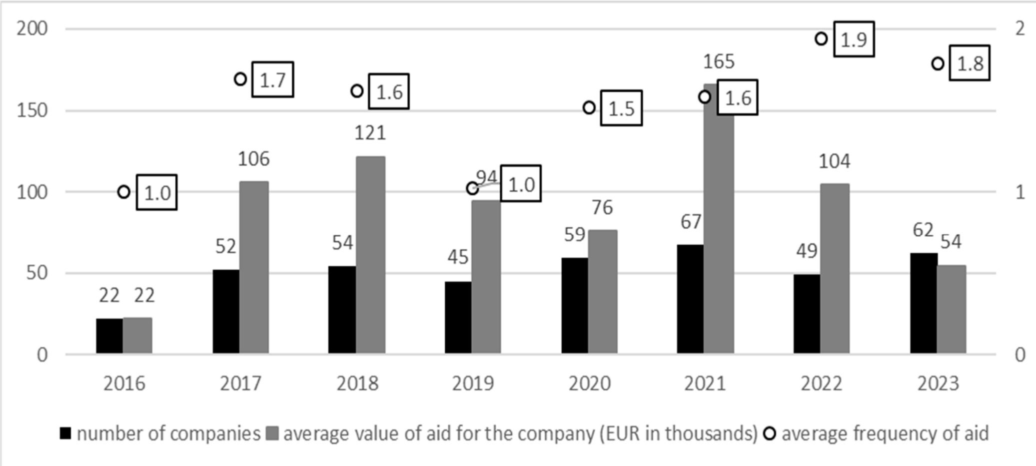

Figure 2. Number of food industry enterprises in Poland covered by public aid for energy-efficiency purposes, average value of aid, and frequency of aid in 2016–2023. Source: own work based on [131].

In the years 2016–2023, we observed a very large variation between the individual sectors of the food industry in terms of the public aid received for energy-efficiency purposes (in terms of its amount and value) (Table 4). The most significant aid, i.e., EUR 12.6 million, went to the meat processing and preserving industry and to the production of meat products. Therefore, with only 36 cases of aid, the average value of the aid measure was also the largest (over EUR 350,000).

Table 4. The value of public aid for energy-efficiency purposes in various food industries in Poland.

Group	Frequency of Aid	Value of Aid (EUR in Thousands)					
		Sum	Average	Median	Min	Max	Vs (%)
10.1	36	12,647.05	351.31	34.18	0.04	3111.29	186.99
10.2	1	27.89	-	-	-	-	-
10.3	435	8709.02	20.02	4.81	0.01	627.42	230.11
10.4	56	1361.81	24.32	10.05	0.59	116.06	117.89
10.5	21	5579.11	265.67	189.76	20.93	741.29	94.40
10.6	21	915.12	43.58	5.90	0.12	760.48	368.36
10.7	28	1956.07	69.86	38.33	8.46	398.80	115.93
10.8	10	1411.46	141.15	40.40	18.18	926.47	188.10
10.9	9	2724.06	302.67	102.60	16.58	935.65	110.65
11.0	31	5781.72	186.51	17.25	0.52	1688.70	211.24

Vs—coefficient of variation. Groups: 10.1 processing and preserving of meat and production of meat products; 10.2 processing and preserving of fish, crustaceans, and molluscs; 10.3 processing and preserving of fruit and vegetables; 10.4 manufacture of vegetable and animal oils and fats; 10.5 manufacture of dairy products; 10.6 Manufacture of grain mill products, starches, and starch products; 10.7 manufacture of bakery and farinaceous products; 10.8 manufacture of other food products; 10.9 manufacture of prepared animal feeds; 11.0 manufacture of beverages. Source: own work based on [131].

The lowest aid (one aid measure—amounting to nearly EUR 28,000) was provided to the industry dealing with the processing and preservation of fish, crustaceans, and molluscs. In contrast, the fruit and vegetable processing and preservation industry used the allotted aid most frequently (435 cases in total), which meant that despite the relatively high amount of provided aid, on average, there was only EUR 20,000 allocated per aid measure. In industries dealing with the production of oils and fats of vegetable and animal origin; the production of cereal mill products, starches, and starch products; and the production of other foodstuffs, the value of the aid provided did not exceed EUR 2 million. On the other hand, in the industry producing ready-made feed and animal feed, the dairy industry, and the beverage industry, the value of the aid granted was relatively high (from EUR 2.7 to EUR 5.8 million), which, when accompanied by a low frequency of granting aid (from 9 to 31 cases), generated a high average value of the individual aid measures (from EUR 186.5 thousand to EUR 302.7 thousand). At the same time, there was a very large variation in the value of the aid provided between the industries. Therefore, for half of the aid measures, their value was much lower than the mean value. This is particularly evident in the case of industries where the difference between the extreme values was very large. In some industries (meat, beverages), the range was even above EUR 1 million. Overall, the minimum value of aid ranged from EUR 0.01 thousand to EUR 21 thousand, while the maximum value ranged from EUR 0.1 million to EUR 3.1 million.

In the period in question, there were 179 companies that benefitted from the allotted aid, of which the majority were involved in fruit and vegetable processing (67), meat (29), bakery (23), dairy (15), and beverage production (13) industries (Figure 3). These industries (apart from bakery) were also characterised by having high average support awarded per company (from EUR 130,000 to EUR 445,000) due to the large amount of aid granted. Herein, the companies that received aid most often came from the oil and fat industry (9.3) because, in total, there were few companies that benefitted from such public aid (6). Only three industries benefitted from public aid offered every year, i.e., the fruit and vegetable, oil and fat, and beverage industries. In the case of the last two industries, this concerned a small number of entities, so most participated in the aid programme quite regularly.

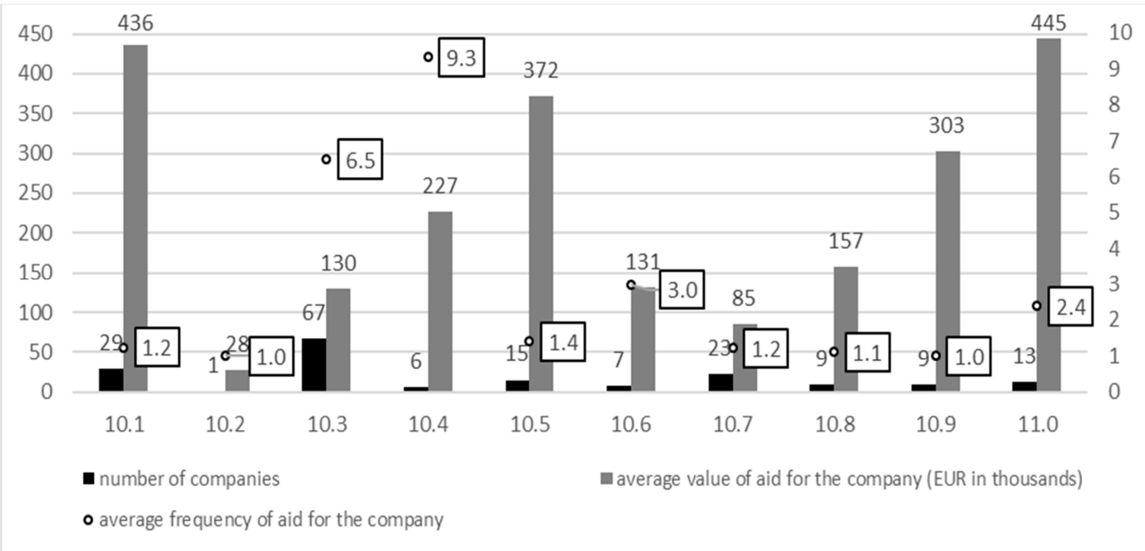

Figure 3. Number of enterprises in Poland covered by public aid for energy-efficiency purposes, average value of aid, and frequency of aid in various food industries. Source: own work based on [131].

On a yearly basis (Table 5), every year (apart from 2022), aid addressed to large enterprises was greatest, as was the average value of aid per beneficiary in this group of entities (apart from 2017). Indeed, throughout the period under review, large entities received EUR 24.2 million, i.e., 58.9% of all funds; medium-sized entities obtained 23.5%; small enterprises gained 15.9%; and micro-sized ones secured only 1.7% (and were also the ones to use aid the least frequently). On average, each of the types of entities received financial assistance no more than twice each year.

Table 5. Level of public aid for energy-efficiency purposes granted to micro-sized, small, medium-sized, and large food industry enterprises in Poland.

Year	Number of Enterprises				Frequency of Aid				Value of Aid (EUR in Thousands)			
	Micro	Small	Medium	Large	Micro	Small	Medium	Large	Micro	Small	Medium	Large
2016	0	2	10	10	0	2	10	10	0.00	37.75	128.00	323.26
2017	1	10	18	23	2	16	29	41	102.26	849.26	2097.41	2458.60
2018	5	14	17	19	5	19	29	36	134.70	1303.03	706.40	4535.39
2019	3	6	15	23	3	6	16	23	130.01	73.21	1538.71	2692.58
2020	3	13	18	26	3	15	30	43	115.04	334.52	725.77	3368.24
2021	7	15	23	22	7	21	39	39	190.51	3720.89	892.19	6280.95
2022	0	6	23	19	0	10	45	38	0.00	85.75	2664.18	2251.44
2023	2	7	28	25	2	10	50	49	34.20	120.68	929.29	2289.08
Total	21	73	152	167	22	99	248	279	706.72	6525.09	9681.95	24,199.55

Source: own work based on [131].

We noted a very high level of concentration of the funds received. Herein, in the meat industry (group 10.1), four enterprises (three large and one small) received almost EUR 8.5 million, i.e., 67% of all funds directed to this industry (Table 6), and each entity received between EUR 1 million and EUR 3.1 million. The beverage industry (11.0) also revealed a high level of concentration, and of the companies in this sector that received at least EUR 1 million of aid, two medium-sized entities were allotted almost EUR 3 million, i.e., more than 51% of all funds. In the dairy industry (10.5), two large dairies received at least EUR 1 million, and another seven dairies (including six large and one medium-sized) received from EUR 100,000 to EUR 1 million. These entities accounted for EUR 5.4 million, i.e., for over 97% of all funds from that industry. In other industries, the degree of concentration of the value of aid measures for entities that received from 100,000 to 1 million euros was also high, i.e., from 68.5% (production of bakery products, 10.7), to over 99% (production of oils, 10.4; production of feed, 10.9). In summary, almost 61% of all entities (i.e., 109) were those that received up to EUR 100,000 of aid, but the aid value constituted EUR 3.5 million, i.e., 8.6% of all funds allocated to the food industry.

Table 6. Degree of concentration of the value of aid for energy-efficiency purposes in various food industries in Poland *.

Value of Aid for One Entity (EUR in Thousands)	10.1		10.3		10.4		10.5		10.6		10.7		10.8		10.9		11.0	
	N	V	N	V	N	V	N	V	N	V	N	V	N	V	N	V	N	V
(0–1)	1	0.04	2	1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<1–10)	2	16.8	7	34.5	1	6.3	0	0	1	6.0	1	8.5	0	0	0	0	2	8.1
<10–100)	14	357.3	35	1580.3	0	0	6	194.2	5	133.7	16	608.2	7	305.3	4	102.1	4	128.9
<100–1000)	8	3802.3	23	7093.1	5	1355.5	7	3338.7	1	775.4	6	1339.5	2	1106.2	5	2621.9	5	2673.6
<1000–3121.5>	4	8470.6	0	0	0	0	2	2046.2	0	0	0	0	0	0	0	0	2	2971.2

* without group 10.2, in which there was one entity during the period under review. N—number of entities, V—value of aid (EUR in thousands). Source: own work based on [131].

There were 16 aid programmes in the years 2016–2023. The largest financial resources, i.e., EUR 14.7 million, were provided via the SA.43907 programme, with aid granted 19 times to 19 entities over five years (2017–2021) (Table 7). The objective of this programme was to implement high-efficiency cogeneration (HC). The source of the funding was foreign. The programme was implemented in various forms, i.e., subsidy (S), fee reductions (F), preferential loans (PL), or conditional forgiven loans (CL). The programme that the entities used most often, i.e., on 249 occasions during the entire period of 2016–2023, was SA.37345. Its value amounted to almost EUR 7.3 million. This was operating aid in the form of a reduction in the amount of the fee (F) for the promotion of energy from renewable sources

(OR). The source of this aid was national. Another important programme was SA.47030, which was used only three times but provided a total amount of over EUR 4 million. SA.47030 offered investment aid for the promotion of renewable energy (IR) in the form of subsidy or other non-repayable benefits (S). The investment programmes SA.43254 (EUR 3.4 million) and SA.43229 (almost EUR 3 million), which were available for five years (2016–2020 and 2017–2021), were also significant in terms of the amount of aid granted. The first was intended for projects supporting energy efficiency in buildings (EE), and the second was for the promotion of energy from renewable sources (IR). Both were provided in the form of grants or other non-refundable benefits (S). A programme which in 2020–2021 was used relatively often, that is, in 68 cases, was the national SA.52530 programme of aid, which lowered the fee (F) for high-efficiency cogeneration (HC). However, its value was relatively low, totalling EUR 190,000. The value of aid granted under other programmes ranged from EUR 73,000 to almost EUR 2 million.

Table 7. Public aid measure for energy-efficiency purposes in food industry enterprises in Poland in 2016–2023.

Years	Aid Programme	Number of Entities	Frequency of Aid	Value of Aid (EUR in Thousands)	Form of Aid	Purpose of Aid
2016	SA.37345 (2015/NN)	21	21	462.54	F	OR
	SA.43254 (2015/X)	1	1	13.28	S	EE
2017	SA.37345 (2015/NN)	34	34	968.31	F	OR
	SA.43229 (2015/X)	5	5	1043.67	S	IR
	SA.43254 (2015/X)	7	8	690.20	S	EE
	SA.43697 (2015/N)	37	37	67.75	F	OR
	SA.43907 (2015/X)	3	3	2727.39	S	HC
	SA.44685 (2016/X)	1	1	10.22	PL	EE
2018	SA.37345 (2015/NN)	32	32	980.50	F	OR
	SA.43229 (2015/X)	12	14	862.65	S	IR
	SA.43254 (2015/X)	6	6	947.17	S	EE
	SA.43697 (2015/N)	35	35	103.55	F	OR
	SA.43907 (2015/X)	2	2	3785.66	S	HC
2019	SA.37345 (2015/NN)	35	35	313.50	F	OR
	SA.43229 (2015/X)	4	4	118.71	S	IR
	SA.43254 (2015/X)	4	4	1496.48	S	EE
	SA.43907 (2015/X)	5	5	2505.82	S	HC
2020	SA.37345 (2015/NN)	32	33	792.29	F	OR
	SA.43229 (2015/X)	13	13	633.95	S	IR
	SA.43254 (2015/X)	4	4	251.73	S	EE
	SA.43907 (2015/X)	4	4	1392.21	S	HC
	SA.44685 (2016/X)	2	2	119.75	PL	HC
	SA.47030 (2016/X)	1	1	998.65	S	IR
	SA.52530 (2019/N)	32	32	150.61	F	HC
	SA.55396 (2019/X)	2	2	204.40	S	IR
2021	SA.37345 (2015/NN)	38	38	943.36	F	OR
	SA.43229 (2015/X)	13	13	304.00	S	IR
	SA.43907 (2015/X)	5	5	4281.50	S	HC
	SA.47030 (2016/X)	2	2	3028.45	S	IR
	SA.52530 (2019/N)	36	36	39.77	F	HC
	SA.55396 (2019/X)	3	3	136.28	S	IR
	SA.59143 (2020/X)	3	3	72.96	S	IR
	SA.59387 (2020/X)	1	1	371.59	S	IR
	SA.64582 (2021/X)	3	5	1906.63	S	IR

Table 7. *Cont.*

Years	Aid Programme	Number of Entities	Frequency of Aid	Value of Aid (EUR in Thousands)	Form of Aid	Purpose of Aid
2022	SA.101484	2	4	327.46	CL	HC
	SA.101484	1	1	6.10	PL	EE
	SA.101484	2	2	270.14	PL	IR
	SA.101556	3	3	1228.62	S	HC
	SA.101607	4	4	1377.18	S	IR
	SA.101633	1	3	683.18	S	EE
	SA.37345 (2015/NN)	40	40	1049.46	F	OR
	SA.43697 (2015/N)	36	36	59.23	F	OR
2023	SA.101484	3	3	409.23	PL	IR
	SA.101484	1	1	71.36	CL	HC
	SA.101607	6	6	81.29	PL	IR
	SA.37345 (2015/NN)	50	50	2729.74	F	OR
	SA.43697 (2015/N)	51	51	81.62	F	OR

F—lowering the fee, S—subsidy or other non-refundable benefit, PL—preferential loan, CL—loans conditionally forgiven, OR—operating aid for the promotion of energy from renewable sources, IR—investment aid for the promotion of energy from renewable sources, HC—aid for high-efficiency cogeneration, EE—investment aid for measures supporting energy efficiency. Source: own work based on [131].

Most programmes (as many as 11) took the form of subsidies. More than three-fourths of the value of the aid granted, i.e., EUR 31.1 million, took the form of a subsidy or other non-refundable benefit (Figure 4) and was given over 118 times. Most often, as many as 510 times, the aid took the form of a reduction in the amount of fees, which constituted 21.3% (EUR 8.7 million) of the value of aid for the sector. Three programmes were provided in this form. The other two programmes were preferential or conditionally forgiven loans, which made up 3.2% of the aid value. Almost half of the funds were allocated to the promotion of energy from renewable sources (Figure 4). Still, 28.8% (i.e., EUR 11.8 million) was allocated to investment aid for the promotion of energy from renewable sources, mainly in the form of grants or other non-repayable benefits. This objective was pursued 81 times. Another 20.8% of all available funds (EUR 8.6 million) was directed towards promoting energy from renewable sources in the form of operating aid as a reduction in the amount of fees. This objective was the most often implemented, with 442 cases. The second most important objective of the aid received was high-efficiency cogeneration. EUR 16.6 million was allocated for this purpose, i.e., over 40% of all funds. This task was implemented in 97 cases. EUR 4.1 million was allocated for investment aid for projects supporting energy efficiency, e.g., in buildings. This type of aid was granted 28 times.

Large enterprises received the largest share of the funds allocated for operating aid for the promotion of energy from renewable sources (67.3%) and for high-efficiency cogeneration (85.4%) (Figure 5). The advantage enjoyed by large entities is more clearly visible in terms of their greater share in the value of aid than in the frequency of receiving aid (they practically did not participate in the allocation of funds for energy efficiency). In the case of investment aid for the promotion of energy from renewable sources, the largest beneficiaries were small entities (41.9%), and in the case of investment aid for measures supporting energy efficiency, they were medium-sized entities (61.8%).

The meat processing industry received the most funds for investment aid for the promotion of energy from renewable sources (47.1%) (Figure 6). In contrast, almost three-fourths of all funds aimed to popularise energy from renewable sources in the form of operating aid were received by the fruit and vegetable industry. Of the funds for high-efficiency cogeneration, the majority was allocated to two sectors, i.e., meat (41.5%) and dairy (26.3%). Moreover, two-thirds of all investment aid for projects supporting energy efficiency was allotted to enterprises involved in the production of beverages. Apart from fish processing, other food industries benefitted from funds directed at various purposes.

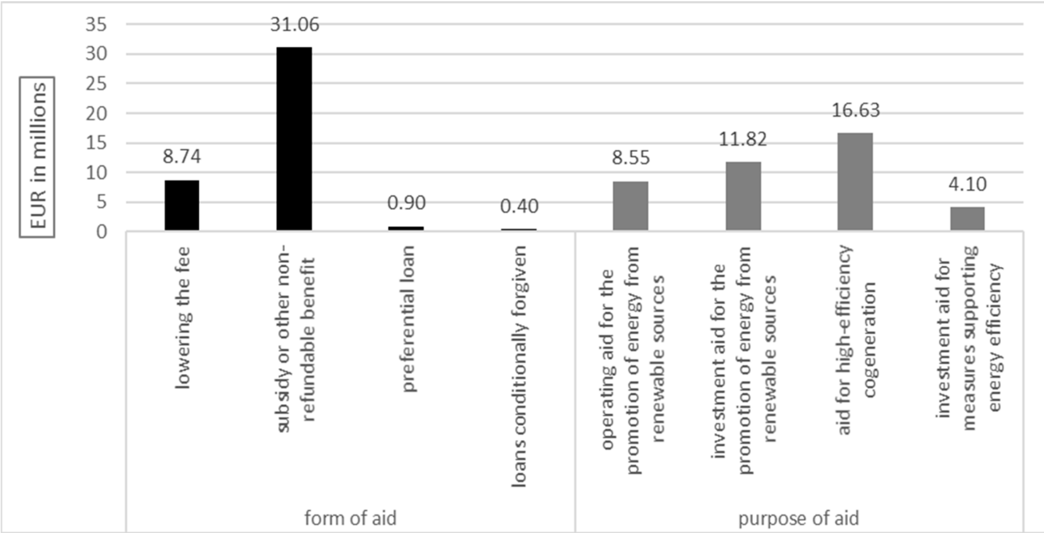

Figure 4. Structure of the aid value according to the form of aid and the purpose of aid for energy-efficiency tasks in food industry enterprises in Poland. Source: own work based on [131].

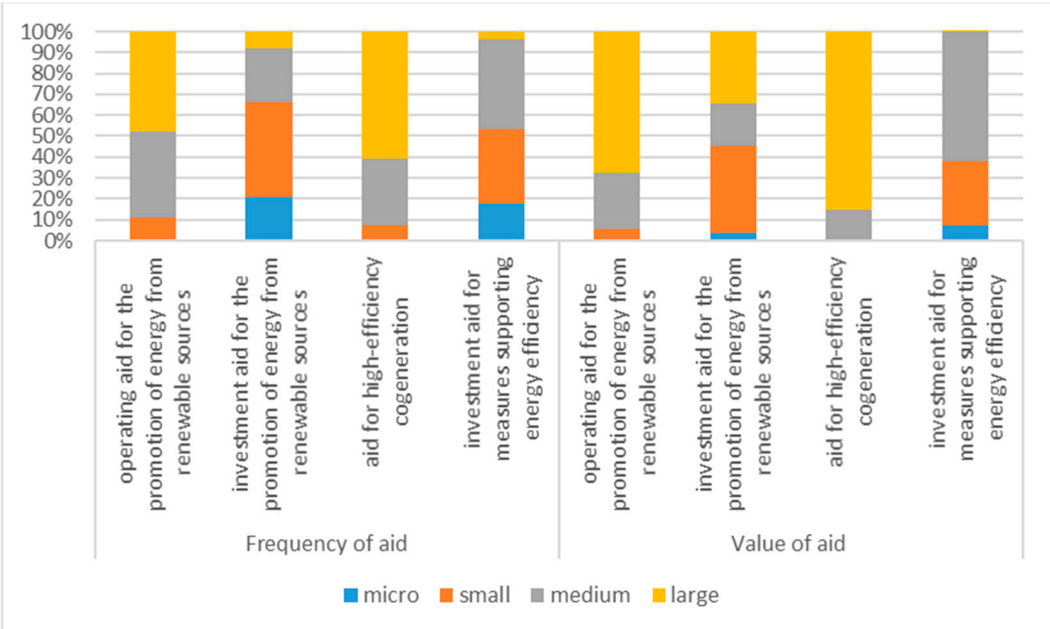

Figure 5. Structure of the value of aid for energy-efficiency purposes, according to the size of food industry enterprises in Poland. Source: own work based on [131].

To determine whether there is a statistical relationship between the value of state aid and other variables, i.e., the size of the enterprise, group of the industry, purpose of aid, or type of aid, the chi-square test of independence was used (Table 8). Since the obtained p-value in each case is greater than the significance level, there are no grounds to reject the null hypothesis that the variables are independent, which indicates the independence of state aid from the size of the enterprise, group of industry, form of state aid, and purpose of aid.

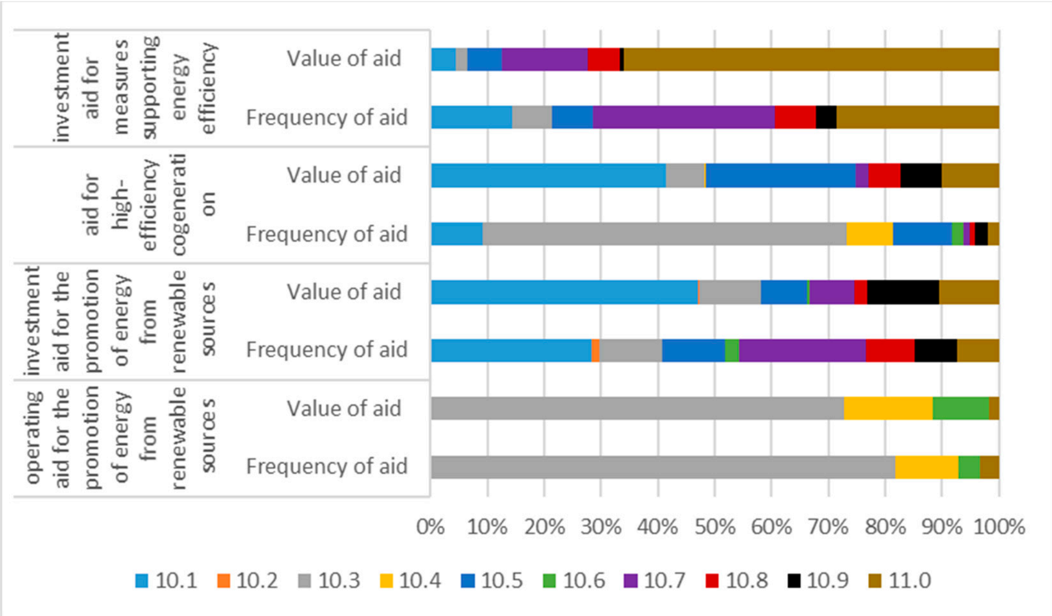

Figure 6. Structure of the value of aid for energy-efficiency purposes, according to the various food industries in Poland. Source: own work based on [131].

Table 8. Results of the verification of the chi-square test for independence (significance level α = 0.05).

Factors	χ^2 Value	Degrees of Freedom	*p*-Value
Size of the enterprise	1922.62	1932	0.556
Group of industry	5832.00	5796	0.367
Form of state aid	1944.00	1932	0.419
Purpose of aid	1939.99	1932	0.445

Source: own work based on [131].

5. Discussion

In answering questions 1–3, an analysis of the legislation and literature shows that EU and national legislators are recognising the growing importance of energy efficiency and its positive impact on environmental protection and the fight against climate change. Efficiency is broadly defined as including the reduction in energy consumption and, among other things, cogeneration, i.e., the simultaneous production of electricity and heat. Such measures help to cut the emissions of greenhouse gases and other harmful substances by reducing the amount of fuel used for combined heat and power generation. Cogeneration continues to be an important part of the electricity and heat production market in Poland. In 2018, cogeneration accounted for 11.6% [100] of electricity generation, and it is increasing every year. The "energy efficiency first" principle was mentioned, e.g., in Regulation (EU) 2018/1999 of the European Parliament and of the Council [134], and implies a comprehensive integration of the energy system, security of supply, and cost-effectiveness, working towards the most efficient solutions for the environment along the entire value chain from energy production to use, e.g., in food processing, transport, and final energy consumption. The idea is to achieve efficiency in both primary and final energy consumption. Reducing energy consumption contributes to an equitable energy transition and reduces energy poverty. It is worth noting that one of the main policy objectives of the European Union is precisely the transition to a climate-neutral and circular economy. The transition needs to be equitable and inclusive. The Union, the Member States, and their regions must therefore take account of the social, economic, and environmental conditions in the countries concerned [135].

The granting of state aid is complicated but possible if the requirements are met, e.g., horizontal aid. EU and national legislators provide funds for investments in renewable energy and other areas of energy efficiency, but their receipt and subsequent disbursement and implementation require compliance with a number of regulatory requirements related to state aid. It is important to note the development not only of legislation but also of policies. Energy efficiency is taken into account in many policies, not only in energy and environmental protection but also in the Common Agricultural Policy. The Polish CAP Strategic Plan 2023–2027 and legal regulations foresee the financing of measures related to renewable energy or the modernisation of buildings [129,130]. Despite very strict state aid rules, the EU legislator provides many examples of permissible state aid, such as horizontal aid. The importance of energy efficiency varies due to different climatic conditions. In countries such as Poland, where winters are cold and there is still a high proportion of coal, investment in renewable energy is particularly important. These investments are financed not only by public funds but often by an entity's own resources or loans.

The research also showed that energy-efficiency tools are diverse. Most of them relate to large enterprises, e.g., energy audits. Member States have adopted the principles of Directive 2012/27/EU, but some have also introduced other legal instruments. For example, in different countries there are tax incentives, access to finance, subsidies or grants, the provision of information and training on energy efficiency, and the use of certification labels. Member States are also responsible for enforcing national legislation implementing the Directive, which only requires that they provide for effective sanctions to ensure compliance with the provisions of the energy-efficiency obligation scheme. Such remarks also came out of studies such as that by [136].

This study and many others deal with the implementation of the 2012 Directive. However, there is a lack of such publications on the role of state aid in achieving the energy-efficiency targets of the food industry in Poland. At the same time, the new Directive 2023/1791 poses innovative challenges regarding the transposition of its provisions into national regulations. Member States are likely to take additional account of their energy-efficiency needs and circumstances. As far as public support is concerned, it can be divided into several types in Poland. According to the Decree of the Minister of Climate and Environment of 23 November 2023 on the list of programmes and financial instruments for projects to improve the energy efficiency of end users, programmes and financial instruments for projects to improve the energy efficiency of end users [128] can be divided into the following: firstly, those for which funds have been obtained from the state budget; secondly, those for which funds have been obtained from the budget of the European Union and from the assistance granted by the Member States of the European Free Trade Agreement (EFTA) or from other foreign sources; thirdly, those for the implementation of funds obtained from the budgets of local government units; fourthly, those for which funds have been obtained from the National Fund for Environmental Protection and Water Management; and fifthly, those for which funds have been obtained from provincial funds for environmental protection and water management. However, only some of these funds can be accessed by entrepreneurs. The majority are addressed to households or municipalities. In addition, public funds from the National Plan for Reconstruction and Increasing Resilience and the Common Agricultural Policy should also be noted.

In summary, the discussion here shows that the framework of the formulation of regulations on energy efficiency is related to the current challenges of climate change, environmental pollution, renewable energy, and increasingly scarce carbon resources. The regulatory framework is very broad. It includes substantive laws of environmental, energy, and financial law and also the administrative procedural regulation of institutions and elements of civil law. The law takes into account political, social, economic, and environmental aspects. Comprehensive legislation is in place to finance investments in energy efficiency, dissemination of knowledge, and innovation in this field. In terms of details, the general provisions of the Treaty on the Functioning of the EU and the Energy Efficiency Directive 2012/27/EU and 2023/1791 of the European Parliament and of the Council should be mentioned first. There are also EU rules on state aid, including horizontal and other rules under other policies such as agricultural and regional, which bring in a wide range of funding opportunities for agri-food entrepreneurs. Guidelines and decisions should also be mentioned. All forms of sources of EU law have been used in formulating regulations on energy efficiency and financing such investments. An extensive regulatory framework also exists at the level of EU Member States' national legislation, as they have implemented the 2012 EU Directive using existing sources of law in their countries. For example, in Poland, there is the Act on Energy Efficiency of 2016, a broad catalogue of Ministry regulations for this legislation. Equally broad and extensive are the regulations on financing energy-efficiency investments. In this regard, there are both acts and Ministry regulations. Some forms of support also occur at the local level, for example, on the basis of resolutions passed by municipalities. There is also wide and extensive legislation and documents on efficiency in other countries outside the EU, such as the USA. Research has shown that the actions of the European Union legislators and national legislators are in line with Transforming Our World: the 2030 Agenda for Sustainable Development, adopted by the United Nations (UN), a programme of action that defines a model for sustainable development at the global level [80].

Answering question no. 4, concerning the scope of state aid for energy-efficiency purposes in the energy-intensive food industry in Poland, it should be stated that between 2016 and 2023, the frequency of granting state support in Poland for energy-efficiency purposes for enterprises involved in the production of food and beverages, the amount of this aid, and the average value of the aid increased. This coincided with a surge in the value of state support for environmental protection and energy purposes in Poland (by 148%) and an enlargement of its share in the value of total state aid from 19.2% to 24.4% [63,64]. Although the scale of support for energy-efficiency purposes for enterprises involved in the production of food and beverages in public funds for environmental protection and energy purposes has clearly increased (by 186%), the share itself remains very low (0.17%). This research is confirmed by in-depth research on the allocation of state aid in a selected food industry, where the entire dairy industry was allocated only 13% of the obtained state support for investments in renewable energy or in high-efficiency cogeneration [67]. Research on the structure of state aid in other EU countries indicates a much higher share of aid for environmental protection and energy than in Poland [65].

Although the level of state analysed aid to the food industry in Poland is increasing (since 2016, it has increased almost sevenfold to EUR 3.37 million in 2023), it remains quite low in relation to the investments made in the sector. Companies in the food industry make high and increasing investments in fixed assets (increasing by 122% from 2010 to EUR 3 billion in 2022). This investment is mainly in the form of machinery and equipment as well as in buildings and structures, which is due to the high and increasing wear and tear of fixed assets [46]. In addition, in the food industry, expenditure on new fuel combustion techniques and technologies for air and climate protection, including the modernisation of boiler and heating plants, is growing (more than 11 times since 2010), although the level of these investments is not very high (EUR 24.5 million in 2022) [46,137].

With regard to question 5, "Does aid to enterprises vary according to the type of food industry, the size of the enterprise, the aid programme, the form of the aid, or its purpose?", we can say that our survey also revealed a very large variation in the amount of state aid received by individual sectors of the food industry. The largest share of the aid, i.e., 30.7%, went to the meat processing and preserving industry and to the manufacture of meat products. More than one-fifth of all aid was allocated to the processing and preserving of fruit and vegetables. Dairies also occupy an important position, with a share of almost 14% of the aid granted. This is justified because the largest share of energy consumption in the production of food and beverages comes from meat, milk, fruit, and vegetable processing [46].

Every year, the largest amount of public aid was received and most often used by large and medium-sized enterprises. Throughout the period under review, large entities received EUR 24.2 million, i.e., 58.9% of all funds; medium-sized entities accounted for 23.5%, small—15.9%, and micro-sized—only for 1.7%. This corresponded to the structure of turnover generated by the food industry, where the share of large entities in the sector's turnover was 59.3% in 2020. This is still a smaller share than, for example, those in France (76%), Germany (70%), or in the UK (72.3%) but still a good result considering the small number of these entities (272) [48]. Research on Polish industrial enterprises indicates that among the various goals of eco-innovation, the reduction in energy consumption during production processes is implemented mostly by medium-sized and large enterprises [138].

The enterprises in the food industry benefitted from numerous programmes, the purpose of which in the field of energy efficiency was focused on three objectives. Almost half of the funds were allocated to the promotion of energy from renewable sources as investment aid in the form of grants or other non-repayable benefits, as well as operating aid as a reduction in the amount of fees due. The second objective of the aid received was high-efficiency cogeneration (over 40% of the funds), and 10% of the funds were allocated to investment aid for projects supporting energy efficiency, e.g., in buildings. This is confirmed by the fact that more and more Polish enterprises in this sector mainly carry out activities in the field of reducing energy consumption by installing more energy-efficient production equipment, energy-saving boilers, energy-saving refrigeration systems, and energy recovery systems [139]. At the same time, in addition to expensive technologies for improving energy efficiency, better energy management is important, such as financing smart metering and monitoring of energy, including its losses [21,45]. State aid programmes took various forms. The most important form (three-fourths of the value of the aid granted) were subsidies or other non-refundable benefits, which were bequeathed 118 times in total. Most often, as many as 510 times, the aid took the form of a reduction in the amount of fees, which constituted 21.3% of the full value of aid for the sector. The loan form was the least frequently used. The multitude of public support programmes and tools, including a large variety of direct subsidies, is typical, as in other EU countries, for the implementation of energy-efficiency policy [140]. In particular, subsidies and access to capital measures are politically and socially popular because they reduce the initial investment costs and eliminate financial barriers hindering energy efficiency [141].

Differences in the value structure of the allocation of energy-efficiency aid according to the size of enterprises, e.g., where we observed the dominance of large entities in aid for high-efficiency cogeneration (85%), is due to the fact that they are very strongly affected by the constant increase in energy consumption and therefore invest in the most modern and energy-saving technologies and processes [142]. Due to their specificity, various food production entities have had different shares in the individual energy-related objectives, e.g., 67.8% of all funds for high-efficiency cogeneration went to the meat and dairy industries, which are very energy intensive due to high production hygiene standards [115]. An example of such activities is the construction of a new unit of electricity and heat generation in high-efficiency cogeneration technology with a total nominal electrical capacity of 0.99 MW by Mlekovita, the largest dairy in Poland [143]. The cogeneration system built at its largest plant ensures the production of electricity in quantities that allow it to avoid the necessity of purchasing electricity from external sources, and the production of heat from cogeneration is used for the production of its dairy products. The project, worth over EUR 1 million, secured one-third of this amount via government funding.

The present study confirms that in the context of climate policy objectives, such a low level of state funds for energy-efficiency purposes for enterprises in Poland, including those in the food industry, may result in the need to increase private spending by these enterprises [66]. This also indicates the need to adapt the country's policy on supporting innovation in the consumption of energy, especially in less technologically advanced sectors, such as agri-food production [144], where processes of diversification of energy sources take place [145]. Sector strategies are important and include designing appropriate instruments to support energy-efficiency policy such as grants, loans, and other forms of public financing [146]. Appropriate policies should be developed to support enterprises in implementing energy-efficiency strategies, especially when changing processes, including purchasing technologies related to intelligent food processing [147] and monitoring energy losses and implementing immediate solutions to avoid them [148]. Taking into account the high costs associated with investments in energy efficiency [149], this is particularly important for the sector of small and medium-sized enterprises in the food industry. These enterprises have less equity capital, and the increase in costs particularly affects their profitability and competitiveness [150].

6. Conclusions

In making this assessment, it is important to highlight the development of energy-efficiency legislation at both EU and national levels. Examples include regulations and directives such as Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955, which states, inter alia, that increasing the EU's energy-efficiency target can lead to lower energy prices and have a decisive impact on reducing greenhouse gas emissions. This can be achieved mainly through reducing energy consumption and improving energy savings; adapting buildings and production, including those related to food, and also through investing in renewable energy and innovative solutions. The legislators rightly point out that energy efficiency is increasingly recognised as an important factor in achieving various societal objectives related to environmental and climate protection, competitiveness, and energy security. Energy efficiency is an important element of EU policy under the European Green Deal. It is important to note the development of public funding opportunities for energy-efficiency measures. In this respect, a regulation on permissible horizontal aid has been adopted, in which the categories of aid specified are compatible with the Single Market and Articles 107 and 108 of the Treaty on the Functioning of the European Union. In Poland, various sources of funding for energy-efficiency measures are in line with EU rules. Investment in renewable energy sources and thermo-modernisation of buildings are increasingly common. Other such measures are important in the food industry, which produces energy-intensive food that is essential for everyone's life. This food should be affordable, and the lower costs associated with energy and energy efficiency will have a positive impact on food and energy security. EU and national legislation is focusing more attention on energy efficiency, emphasising the positive impact on the environment, financial savings, and caring for future generations.

The scope of state aid for energy-efficiency purposes in the energy-intensive food industry in Poland is relatively low. Despite the increase in state aid to food and beverage companies for energy-efficiency purposes, it is still small in relation to both the investments made by companies in the sector and the total amount of state aid in the country. Investment expenditure related to adapting to climate policy requirements is extremely high. For the food industry, which is energy intensive due to its specific technological processes, and which has low profitability, the question of the role of state aid raised here seems to be quite relevant.

The aid for enterprises varies depending on the type of food industry, size of enterprises, aid programme, form of aid, and its purpose. As most of the aid has been assigned to large and medium-sized enterprises, this may indicate that small enterprises have not yet started to adapt and will require even greater state support to implement eco-innovations in the field of energy. The tightening of climate policy will boost the importance of the energy saving target in the coming years, which should be reflected in an increase in the value of aid granted to companies for this purpose. The contemporary geopolitical situation indicates that while improving energy consumption in the food industry is advisable for reasons of cost competitiveness or growing environmental requirements, it requires spreading over time. Due to the fact that investments in this area often exceed the financing possibilities by enterprises, state support is important.

It should also be noted that the complexity of regulations, which change frequently, is precisely what leads some entrepreneurs to use their own resources or loans instead of applying for public funds. Many entrepreneurs use public funds for energy-efficiency investments, and with the new EU funding opportunities, the number of beneficiaries will increase.

Our study fills a research gap. The level of public aid for energy-efficiency purposes in the food industry in Poland and all its branches was indicated. Forms of aid and specific goals in this area were indicated. This aid was also analysed in the context of applicable legal acts at the national and EU level.

However, the article does have its limitations; e.g., the impact of energy-efficiency support, such as the number of investments realised, is not indicated. Further research should seek to show the concrete effects of state aid on at least a selected sample of companies. Another issue could be to analyse the criteria employed by the different authorising bodies when granting or refusing state aid. A further step would be to conduct an analysis comparing state aid and its effects on food industry enterprises in different countries.

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Article

List of Issues That Require Legal Regulation as Part of the Renewable Energy Regulation in Component States of Federation

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Abstract: The transition to renewable energy is strongly affected by legal regulation. To increase the efficiency of the introduction of renewable energy into the energy systems of component states of federations and accelerate the energy transition, it is necessary to carry out systematic work to improve regional legislation in this area. The purpose of this study was to analyze the current regulatory legal acts on the renewable energy of the regions of a number of countries such as the USA, Germany, India, Switzerland and Russia in order to form a universal list of issues that need regulation at the regional level. The main methods for achieving the objectives set in this study were the comparative legal method and the method of analysis and synthesis. As a result, a number of recommendations were developed describing how legal relations primarily need to be regulated by regional legislation, and examples of different approaches to their settlement were presented. The issues in need of legal regulation were divided into three groups according to the degree of importance of their regulation by the legislation of the component state of the federation. Further development of this study will be aimed at identifying the most effective industrial practices for resolving each of the issues included in the compiled list which will help improve the efficiency of regional legal regulation of renewable energy.

Keywords: renewable energy source; green transition; energy law; regional legislation; renewable energy policy; regional law; national legislation; lawmaking; environmental law

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1. Introduction

The transition from fossil fuels to renewable energy sources is one of the most important tasks of our time, which is expedient from the point of view of reducing carbon dioxide emissions [1], ensuring energy security [2] and preserving exhaustible raw materials [3]. Successful implementation of renewable energy is determined by a number of factors, including policy and legal regulation in this area. There are a number of works describing the experiences of different countries with the implementation of renewable energy and demonstrating the impact of policies [4], climate factors and level of economic development [5] on the success of such implementation. It should be noted that climatic and demographic factors may differ significantly between different territories of the same country, and in the case of federations, differences in government policies can be expected. Consequently, to increase the efficiency of the introduction of renewable energy into the energy systems of constituent entities of federations and to accelerate the energy transition, it is necessary to carry out systematic work to improve regional legislation in this field. One of the ways to ensure sustainable development is the formation of legislation based on a methodology (Figure 1) based on replication and adaptation of the experience of legal regulation of renewable energy in the component states of various federations that most successfully implement such energy installations in their territory. An important component of this methodology is a list of issues that need legal regulation at the level of regional legislation.

Figure 1. Components of the methodology for the development of regional legal regulation of renewable energy.

For the effective use of such, it is necessary to determine the scope of legal regulation and the forms of its implementation available to each region. In federal states, the division of power between the central government and component states is usually entrenched in the fundamental law of the country. Most of the fundamental laws predate the widespread adoption of energy installations based on renewable energy sources, so relations in the field of renewable energy are in most cases unregulated by fundamental laws. At the same time, the main part of legal relations in the field of renewable energy is an element of energy law and energy policy; therefore, if the fundamental law of the country provides for the classification of energy as the exclusive subject of jurisdiction of the central government, the subject of joint jurisdiction or the subject of jurisdiction of the regions, this includes renewable energy. For example, in Switzerland, the constitution assigns special responsibility to the cantons for measures relating to energy consumption in buildings [6]. Renewable energy development could also be influenced by the policies of other fields, such as innovation policy [7], that also may have its regional level. In addition, energy transition policy largely inherits national regulatory styles [8].

In countries that consider energy to be a regional responsibility, the need for legal regulation of renewable energy at the regional level is obvious; therefore, the necessity of existence of such legislation needs no further discussion. In states that classify energy as a subject of joint jurisdiction, each particular case must be considered separately. If federal legislation is sufficiently developed, and the region does not have unique climatic, demographic or economic characteristics that cannot be taken into account in general federal laws, there is no direct need for regional legislation. The adoption of norms that duplicate federal legislation is not a serious problem for the legal system, but it also does not contribute to the development of regulated legal relations. But in most cases, federations are large countries covering several climatic zones, and the component states have quite unique characteristics including those that matter for the introduction of power plants based on renewable energy sources and for the development of the energy network as a whole, so that direct federal regulation would be less expedient than the adoption of regulatory legal acts in the region itself.

In countries that directly attribute energy to the exclusive powers of the central government, the issue of legal regulation of renewable energy cannot be raised. But even in countries where regulation is carried out primarily at the federal level, component states may still have mechanisms to limit or stimulate the development of renewable energy by regulating other related relations. In the Federal Republic of Germany, energy regulation, including renewable energy, is predominantly federal, but, for example, North Rhine-Westphalia has adopted a regional climate package of acts, which includes goals for the development of carbon capture and storage projects, since there are no federal projects in this area yet developed [9]. And this package can have an impact, among other things, on the development of renewable energy. In addition, different states can use different building codes for these purposes; in the same North Rhine-Westphalia, there was a restriction of 1 km between a wind turbine and residential buildings [10] and on the placement of such devices in forested areas, which were eventually eased [11].

Studies that compare several countries [12–14] show that the correlation between the climatic and demographic potential of renewable energy power plants and the actual success of their implementation is not always completely direct. It continues at the regional level as well; for example, in Alabama, USA, a state with enormous climatic potential for renewable energy, especially solar energy, renewable energy generation is rather underdeveloped. One of the serious factors that affects the implementation of renewable energy generation besides the climatic and other resource potentials is the regulation of this industry within the component state. In a region in which all legal relations in the renewable energy field are precisely and clearly defined, and from the content of regional laws and local acts it is obvious that the population and the authorities of the region intend to increase the share of renewable energy in the overall power generation, large investments in energy and infrastructure are more likely to be made, and small consumers will more easily transit to renewable energy from traditional energy sources.

Legal regulation of renewable energy by adopting only one law with a number of substantive rules, without a set of acts that provide procedural regulation, may also not lead to any results. For example, in the state of Iowa, USA, an act focused on the production of alternative energy was adopted back in 1983, but due to the lack of necessary enforcing provisions it was not actually implemented until 1996 [15]. This highlights the importance of the systematic and comprehensive development of renewable energy regulation.

Hence, a structural and substantive analysis of the legal norms regulating renewable energy power plants in component states that are the most successful with implementing renewable energy generation, taking into account their defining climatic, economic and demographic features, would allow for the development of a methodology for the composition and improvement of effective regional legislation in the renewable energy field.

The unified methodology for the development and reform of regional legislation in the renewable energy field for different component states of the same country also has the advantage of uniformity of legal regulation. Although some flexibility must be maintained to maintain efficiency, a unified structure of regulations, a similar system of regulatory bodies and other reproducible factors can ensure this uniformity. This, first of all, facilitates the work of government and corporate lawyers in organizations that have representative offices and own power plants in several component states of the federation. But it also makes life easier for small consumers, who will not have to face additional difficulties after changing their region of residence within the country.

Some states practice the formation of such methods in relation to their own legal systems. The Conference of Cantonal Energy Directors, which brings together regional bodies that regulate renewable energy in the cantons, has developed a set of joint model cantonal provisions in the energy sector [16], which it updates as necessary [17].

Also, the development of legislation based on a methodology designed for its long-term support and evolution adds political stability. Investors who committed money into renewable energy must be confident that the development strategy will not change, at least in the medium term, and that renewable energy power plants will not lose support [18].

This study is intended to compensate for the lack of methodological materials aimed at improving the development of legislative techniques. Regional legal regulation of renewable energy is implemented in federations everywhere, given a suitable climate, but theoretically grounded guidelines for its development remain rare. Such methodological recommendations can help to strengthen the link between basic legal science and regional lawmaking bodies, to facilitate the development of a normative legal act in case of the need for its early adoption, when there is no possibility to conduct independent detailed research.

The purpose of this study was to formulate a universal list of issues that must be regulated by regional legislation in order to implement effective legal regulation of renewable energy in a region. For this purpose, it was necessary to fulfill a number of tasks: to determine which component states are most effectively implementing renewable energy, taking into account the possibility of reproducing their experience; to establish which issues are regulated most frequently in the legislation of these regions; to analyze what the purpose was behind the inclusion of the identified items in corresponding legislations and how this experience can be reproduced.

2. Materials and Methods

The first part of this study was carried out by analyzing the legislation of the regions of the Russian Federation. The team of authors better understands their political and legal structure and is able to more competently compare the instruments of legal regulation with the general opportunities provided by the legal system, the geographical characteristics of the federation and its component states.

The initial basis for this study was the legislation on renewable energy of the Russian Federation, in which, at first glance at Art. 71 of the Constitution [19] which lists subjects under the exclusive jurisdiction of the federation, the impression might be formed that regions cannot deal with the topic of regulating renewable energy since there is a "federal power systems" clause. However, due to the absence of a definition of the concept of federal power systems in the legislation, and the fact that the draft of federal law "On Federal Power Systems" was withdrawn from consideration more than twenty years ago and was never resubmitted to the parliament, at present the component states of the Russian Federation carry out regional regulation of energy including power plants based on renewable energy sources. In addition, if in the absence of a legal interpretation of the term "federal power systems", its literal interpretation is considered, and then renewable energy power plants that are in most need of a special legal regime, specifically those designed for small- and medium-sized consumers and not connected to the electricity grid, will not be covered by the aforementioned law; with the reduction in powers of the component states of the Russian Federation in the field of energy, this part of it will remain unchanged.

Despite the fact that the first stage of research was carried out on the basis of the regional legislation of the Russian Federation, the hypotheses developed in the process were confirmed or studied by cross-checking them during the analysis of the regional legislation of a number of other countries, such as the United States of America, the Federal Republic of Germany and others. With all the features associated with political processes, the Russian Federation still serves as a good basis for such study since its regions are very diverse in climate, demographics, economics, in the availability of traditional energy sources and in the prevalence of grid connection. A large amount of raw hydrocarbon reserves, large hydroelectric power plants and nuclear power plants may seem to be a significant distorting factor, since for many component states of the Russian Federation the introduction of renewable energy power plants is a matter of environmental priorities, ensuring "carbon neutrality" and maintaining the energy security of the region and individual settlements, but the existence of a number of regions in which there are serious and insurmountable obstacles to energy supply from traditional energy sources, on the contrary, ensures the diversity and the meaning of the regional legal regulation. In addition, access to a large amount of hydrocarbon raw materials itself does not mean low demand for green technologies. For example, in the USA, the state of Texas is a leader in the production of crude oil and natural gas, but at the same time it is a leader in the generation of wind energy and is second in the country in solar energy. The key components of the methodology are not tied to specific territories but are aimed at creating tools that allow for the development of norms taking into account the defining features of the region. Most of the methodology is devoted to answering not the question "How to regulate correctly?" but the question "What needs to be regulated and what options are there to do this?". Hence, the entire methodology, or at least most of its provisions, including the questions discussed here that require legal regulation at the regional level, can, with certain adjustments to the legal system and the nature of the relationship between the federal and the regional governments, be reproduced in other countries even if they differ in the energy balance.

After completion of the first stage of this study, when the main working hypotheses were formed, and the mechanism for analysis of the regional legislation was worked out, in order to expand the base of sources, double-check and supplement the formulated hypotheses and increase the flexibility of the developed methodology, this study was broadened on the legislation of component states of other federations that successfully implement renewable energy.

Important sources of information for Russian regions are investment ratings in the field of renewable energy sources, and the main of which is the rating compiled by the Russia Renewable Energy Development Association (RREDA) [20].

The algorithm for determination of successfulness in implementation of renewable energy (Figure 2) is as follows.

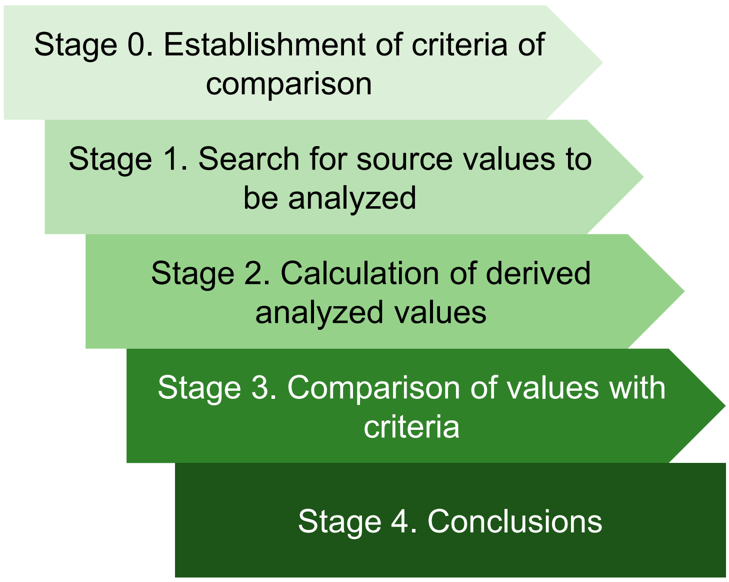

Figure 2. Algorithm for determination of regions most successful with implementing renewable energy.

At the preliminary stage (Stage 0), performance evaluation criteria are established by which the regions under consideration will be assessed, and the baseline values for the comparison are found. The selection of criteria depends on the purpose of the study. In our study, the baseline for gross potentials of renewable energy sources was the average value for the regions of federation, and the baseline value of any other value was the average value from those regions that generate meaningful amounts of renewable energy.

At Stage 1, the values for comparison that cannot be calculated are obtained from external sources. The types of values include gross potentials of renewable energy sources, installed capacity of renewable energy power plants and all types of power plants, total annual energy generation and annual renewable energy generation, capacity of newly installed renewable energy power plants and funding provided by government programs aimed at aiding the implementation of renewable energy. The potential of renewable energy sources in each region is obtained from maps and directories of renewable energy resources, energy agencies, government statistical bodies and other sources. The source data on the installed capacity of generating facilities and the amount of energy generated and consumed per year are found in reports of federal and regional energy network operators, reports on the operation of generating facilities, data from energy agencies, statistical bodies of the state and other sources. The budgets of funding of measures for the development of renewable energy can be found in texts of federal and regional programs aimed at increasing energy efficiency, energy saving and the use of renewable energy sources and in reports of energy agencies, statistical bodies of the state and other sources.

At Stage 2, the derived values are calculated from the source data or found in the sources that report such values. The derived values include share of energy generated by renewable energy installations from the total gross energy potential, the share of renewable energy generation in the regional energy balance, the share of renewable energy in fulfillment of regional energy demand, the installed capacity of renewable energy power plants sufficient for fulfillment of the existing deficiency of regional energy balance, the installed capacity of renewable energy power plants that would allow fulfilling regional energy demand solely by renewable energy sources, funding spent per unit of installed capacity of renewable energy power plants and funding spent per unit of generated renewable energy.

The share of energy generated by renewable energy installations from the total gross energy potential can be determined for each type of renewable energy source separately and for the total gross potential of renewable energy sources using the following (Equation (1)):

$$\eta_{RGP} = W_{RES}/W_{GP}, \tag{1}$$

where W_{RES} is the annual generation of energy from renewable energy source, kWh, and W_{GP} is the annual gross potential of renewable energy source, kWh. However, this parameter significantly depends on the area of the region under consideration. In order to reduce the effect of area, the values of the specific gross potential and specific generation can be used for calculations by Equation (2):

$$\eta_{SRGP} = W_{SRES}/W_{SGP}, \tag{2}$$

where W_{SRES} is the specific energy generation by a renewable energy installation per 1 km^2 of occupied area, $kWh*km^{-2}$; W_{SGP} is specific gross potential of the energy source, $kWh*km^{-2}$. It should be noted that for different types of renewable energy sources, this parameter will significantly differ since the conversion coefficient of different types of energy resources significantly varies.

The share of renewable energy sources in the energy balance of the region shows the contribution of renewable energy power plants in the total energy generation; this parameter allows assessing the scale of implementation of renewable energy sources in the region. It should be noted that for regions with large energy production, it is more difficult to achieve high values of this parameter since the total capacity of renewable energy power plants must also be high. A similar parameter is the share of renewable energy sources in fulfillment of the energy demand of the region. Here, it is important to note that larger demands are harder to fulfill, and in evaluation of success of introduction of renewable energy facilities, smaller absolute value of renewable energy generation may result in larger values of generation-to-demand ratio if the demand itself is modest; see an example in Figure 3, where moderate generation in the Russian region of the Republic of Kalmykia covers a much larger fraction of regional demand in comparison with the much larger generation of Stavropol region covering a smaller fraction of regional demand. This parameter is especially relevant for energy-deficient regions, since these regions are energy-dependent, which negatively affects their energy security. For such regions, it is necessary to determine what installed capacity of renewable energy power plants will be sufficient to cover the demand of the region. To analyze the effectiveness of government incentives for the use of renewable energy sources, it is necessary to estimate the increase in power per budget spent on funding of the incentive.

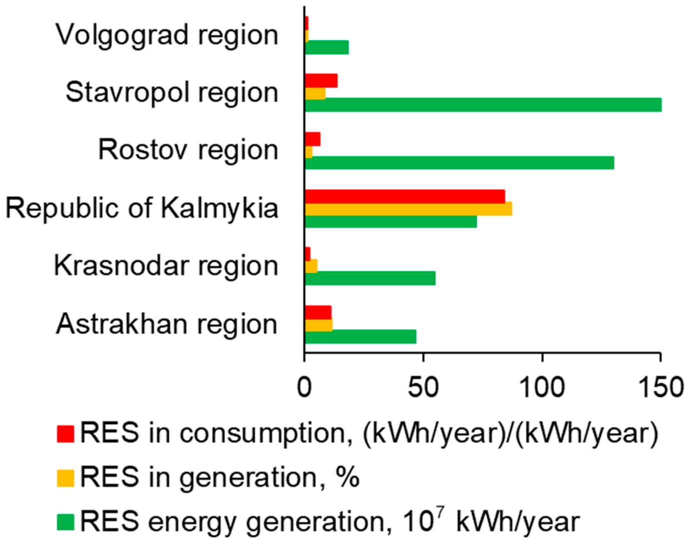

Figure 3. Total annual generation from renewable energy sources and its role in energy balance of several regions of the Russian Federation.

At Stage 3, the assessment of success of the introduction of renewable energy power plants in energy systems is carried out by comparing calculated parameters with baseline values in established criteria. Based on the results of the assessment, at Stage 4 the regions are ranked by successfulness of implementation of renewable energy power plants into regional energy systems.

For each region examined, the existence of legal regulation of renewable energy and energy in general in the statutory document of the region was checked. This is not the most common occurrence, but examples include Alaska, USA, where a grant fund for the development of renewable energy is provided for in the statutory document [21], and North Dakota, USA, where renewable energy targets are included in the Century Code [22]. Then, the specialized thematic regional laws dedicated to renewable energy were considered. Then, regional laws on energy saving and increasing energy efficiency, if they contained provisions related to renewable energy, were analyzed. Then, the provisions on power plants operating on the basis of renewable energy were searched for in the regional laws on ecology, on investment activities, on land-use procedures, on limiting of anthropogenic impact, on tax benefits and concessions, on administrative responsibility, on gasification and on farming. Acts inferior in legal force to the laws of the region were also added to the consideration, such as regional government-funded programs dedicated solely to renewable energy and to energy saving or renewable energy and provisions on competitions and investment projects in the field of renewable energy.

We studied the regional programs of the federative entities that were most successful in implementing renewable energy in their regions, if these programs were entirely dedicated to renewable energy, had a subprogram dedicated to renewable energy or had a broader theme but had a significant set of activities aimed at renewable energy development. If an eligible region simultaneously implemented several different programs devoted to renewable energy, we did not make any additional selection but included all programs with activities devoted to renewable energy development in our analysis. Additionally, we also supplemented the individual theses with programs from other entities if they used unusual methods and approaches.

For each region, a list of bodies was compiled with indication of the limits of their powers in the field of regulation of renewable energy sources. The most important acts adopted by these bodies that determine the legal status of renewable energy sources in the region were also added to the system of regulatory legal acts.

An analysis was carried out of the appropriateness of the use of technical terms in the reviewed regulatory legal acts. The numerical values of physical quantities were scrutinized and compared with climatic conditions and operational characteristics of renewable energy installations. In certain provisions of regulatory legal acts that were related to the legal regulation of the direct operation of power plants, the consideration of the power plant design as well as the process of their construction, commissioning, scheduled maintenance, emergency repairs, decommissioning and dismantling were analyzed.

Further work on analyzing the content of the formed base of regulatory legal acts regulating renewable energy in the constituent entities began with compiling a list of legal regulation issues raised in them. From all the texts of normative legal acts of each examined region, a list of issues regulated in them was formed. From these, a consolidated list was compiled where the issues were sorted by weight, and the weight was determined by the number of regions in which the issue was regulated. The final consolidated list included issues that were regulated in more than half of the regions under consideration, and the present article focuses on eight issues that received the greatest weight based on the results of the analysis.

Legal principles were identified that were followed in each of the component states in lawmaking in the field of renewable energy. Also, the analysis of legal principles was supplemented by the analysis of the purposes of laws, if they were declared in them. A list of additional positive practices was also compiled, the adoption of which should have a positive impact on the effectiveness of legal regulation of renewable energy by a specialized regional law, and justifications for the usefulness of these practices were prepared.

3. Results and Discussion

3.1. The List of Questions Is an Important Component of the Methodology

The list of questions that require legal regulation at the regional level is one of the key components of the methodology for improving regional legislation in the field of legal regulation of renewable energy power plants. The determination of a list of questions that are regulated by the legislation of regions that are most successful in implementing renewable energy was precisely one of the primary tasks in developing the methodology.

Many other components of the methodology represent a detailed disclosure of options for legal regulation of each of the questions that need such regulation. The methodology is meant to be modular, and each individual component can be used independently of the others, but it seems most appropriate to consistently modernize legislation on all proposed questions. Legal regulation of renewable energy at the regional level is usually a complex system in which some elements significantly influence others. Gaps in the resolution of some questions may devalue the achieved results in the legal strengthening of the regulation of others. Hence, it is advisable to use the formulated list of questions that need legal regulation as part of the regulation of renewable energy in a region.

In addition, one of the purposes of forming the list of questions is to serve as a kind of checklist in writing a regional law on the regulation of renewable energy power plants or an amendment to a number of regulatory regional legal acts that regulate these relations. The list itself cannot suggest ready-made optimal solutions or eliminate conflicts, but its use, adjusted for the energetic and demographic potentials of a component state and its level of freedom in the legal regulation of this industry should help prevent the emergence of gaps.

3.2. The Need to Adopt a Separate Regional Law

There are three fundamentally different approaches to the legal regulation of renewable energy at the regional level. Each of them has its own advantages and disadvantages, and the choice rather depends on the current practice of industry legislation at the regional level in a country.

The first approach is to adopt a specialized regulatory legal act specifically dedicated to the regulation of renewable energy power plants. This approach is common, for example, in the USA, where many states have their own regional acts, but in the Russian Federation, as an example, only two regions can be cited—the Republic of Sakha (Yakutia) [23] and the Krasnodar region [24], which are as dissimilar to each other as possible in terms of climatic conditions, demographic and economic characteristics. This illustrates that the choice of how to consolidate the norms governing renewable energy is determined precisely by the legal practices adopted in the region.

The second approach involves establishing the norms governing renewable energy power plants in sections of laws on energy saving or on increasing energy efficiency. The third is the distribution of norms across a variety of regulatory legal acts on the environment, building standards, gasification, heating and so on, without incorporating them into one single document.

There are a number of advantages to adopting a specialized law dedicated exclusively to renewable energy sources. Firstly, it simplifies the work of lawyers, small consumers and investors in finding the necessary information before implementing the appropriate energy installations. Secondly, it is easier to keep one normative legal act up to date and consistent with both the economic and environmental agenda than track a set of norms distributed across many normative acts. However, this effect is also achieved by creating a specialized section in the law on energy efficiency. Thirdly, the adoption of a specialized law signals to consumers and investors that regional authorities take renewable energy seriously. In most countries of the world, only significant legal relations are regulated precisely at the level of adoption of a separate regional law, and this increases confidence in regulated relations.

Undoubtedly, the key factor here is the prevailing practice in a country. The existence of laws on renewable energy in other regions is a significant incentive for choosing this particular approach for three reasons. First, the law could be developed based on the norms of those regions that have been most successful in introducing renewable energy power plants into their energy systems. Secondly, when other regions introduce promising novels in law, it will be easier to adapt and reproduce them under the same structure of legal regulation. Thirdly, investors coming from other regions, as well as small- and medium-sized consumers who are relocating, will have the opportunity to work with legislation similar to their previous experience.

On the other hand, all of the above points also apply to the situation where all the rules governing renewable energy are collected in one section of the act dedicated to broader energy topics. Here, however, it should be taken into account that a situation may arise where in different regions these are sections of different laws (for example, on energy saving, energy efficiency or regional energy systems), so in the matter of convenience this approach is inferior to a specialized regulatory legal act.

The current practice in countries with regulation distributed over many acts is not so appropriate for reproduction. When developing a regional law, one can still rely on the norms of the most successful regions, simply adding the necessary fragments to the consolidated act or references to the norms of other acts. At the same time, reproducing practices by copying them into similar acts does not provide any advantages and, moreover, may be complicated by the fact that the list of normative legal acts adopted by regions may differ, or the subjects regulated by acts of the same name may differ.

The current practice in the Russian Federation clearly illustrates that the adoption of a specialized regional law in itself is not a prerequisite for effective legal regulation of renewable energy power plants. Nine of the ten regions which were found to be most successful by the RREDA agency [20] do not have a specialized law. In four of these nine regions, the norms are collected in one law on a broader energy topic; in the rest, they are distributed across a large list of regulatory legal acts. In the United States of America, some states such as New Jersey, Washington and New York have dedicated laws on renewable energy sources while a number of states, e.g., Illinois, have included renewable energy regulation in their "clean energy" laws. This is a broader concept [25], but renewable energy is an important part of it. The example of the legal regulation of renewable energy in the Federal Republic of Germany also illustrates that the adoption of a specialized regional law is not necessary, as none of the German lands have adopted one. Neither approach demonstrates any obvious advantages when it comes to theoretical assumptions, but there are advantages to the actual implementation of renewable energy power plants into regional energy systems. When the state-level renewable portfolio standard was first introduced in the United States of America, the studies showed its significant positive effect on the development of renewables [26,27], but recent analysis [28] of the influence of state and federal regulation on renewable energy generation "calls into question the need for state-level renewable portfolio standard initiatives to mandate the adoption of renewable electricity generating capacity". Hence, the relative roles of federal-level and state-level regulations and incentives remain unclear.

It should be noted that despite the current practice in the other regions of a country and any other additional assumed advantages, if the region already has a regional law on renewable energy, all further work should be carried out on its improvement. Changing the approach and transferring norms to other regulatory legal acts is extremely undesirable. Without abandoning the current law, this will create duplication of rules, leading to a more complex legal framework that will not only confuse generator companies and energy consumers but will also create room for mistakes by legislators. The repeal of a specialized law might have two negative consequences. Firstly, the need to preserve its necessary provisions in the form of norms of other normative legal acts so as not to miss anything, not to create conflicts and not to complicate the structure of recipient acts creates a large burden on the legislative body and its apparatus. Secondly, the cancellation of a regional act of this type looks like a negative news feed, and if the media would not reflect the entire context that the pre-existing norms will be preserved in other regulatory legal acts but would present the news in a simplified manner, the investment climate for projects in the field of "green energy" could be spoiled, and public protests among the environmentally conscious population may arise.

3.3. Which Energy Sources Are Considered Renewable?

Regardless of whether the regional legal regulation of renewable energy power plants is concentrated in one act or distributed over many, a list of questions that must be covered by it might be determined, and the first such question is which energy sources are classified as renewable in the regional legislation.

One of the reasons for the need to strictly regulate this question is that the use of renewable energy might provide certain privileges, benefits and concessions, and it may be beneficial for large business entities to lobby for the application of these measures to their facilities that use energy sources different from traditional ones, even if they are not considered renewable, taking advantage of gaps in legal regulation. The second reason is that unscrupulous performers could also use an insufficiently strictly defined list of renewable energy sources and use cheaper and simpler but less efficient and less environmentally friendly technologies related to renewable energy in order to meet target reported indicators.

It should also be taken into account that each region has its own unique resource potential, and it is not always advisable to extend a privileged position to all existing renewable energy sources, since the use of some of them in the region may be inappropriate and may not suit the needs of both direct energy consumers and the entire population of the region. For example, hydropower often does not require additional support because it is more cost-effective than other renewable sources even without additional measures, it creates competition with other types of renewable energy and has a negative impact on the environment.

If federal legislation has already adopted an exhaustive and unproblematic list of renewable energy sources, there is no need to duplicate it at the regional level, and it would be better to use the blanket norm.

If federal legislation does not contain a specific list but only provides a general description, if the list is open or if the list is completely absent, regulation at the regional level is necessary. It may be enshrined in a separate article of a normative legal act or contained in an article containing definitions of terms. Another way to establish such a list is a blanket norm with reference to the acts that will contain it and will be inferior in legal force to the laws of the region. This also makes sense as a temporary measure taken in order to simplify the process if it is expected that changes will be made to the list. To avoid the previously mentioned abuses, the list should be made closed and it should be based on environmental and economic indicators and on the resource potential of the region.

The most unfavorable scenario for regional legal regulation is when federal legislation approves a list of renewable energy sources, but it is not optimal for the region. In this case, everything depends on the format of distribution of subjects of authority between the central and regional governments. If the degree of freedom available to the region allows changes to be made to the list of renewable energy sources, it is advisable to make a note in the corresponding article that the list is relevant specifically for the region and differs from federal legislation.

Sometimes, a situation may arise when, for both socio-economic and environmental reasons, it would be advisable to equate one of the non-renewable energy sources with renewable ones, extending all the provided benefits to energy installations based on them. This is not the best practice, as it creates room for mistakes in the further maintenance and reproduction of legislation, including possible mistakes in replication by other lawmaking entities. It seems more reasonable either to adopt a separate regulatory legal act that would indicate that, in certain aspects, power installations based on a given energy source are subject to a legal regime similar to the regime set for power installations based on renewable energy sources or to adopt a separate regulatory legal act in which the rules will be duplicated.

For example, in California, USA, renewable energy sources encompass renewable biomass (solid fuel, solid waste to energy and biogas), wind, solar, geothermal energy and hydropower. The suitability of biomass-based energy for decarbonization and feasibility of bioenergy-focused renewable energy systems is debated [29,30], and several studies highlight the ecological disadvantages of growing crops specifically for biomass-based energy generation [31]. At the same time, there is a discussion about the inclusion in this list of some non-renewable technologies such as fuel cells that have the main advantages of renewable ones [32]. The main criterion is the proximity to zero carbon footprint, that is, decarbonization is the basis of the energy transition.

Sometimes, it was considered beneficial to encourage certain practices based on the types of energy installations that are most in demand in the region. For example, in the Indian state of Gujarat, additional incentives are provided for hybrid energy plants that combine several energy sources [33].

A very detailed closed list of energy sources classified as renewable can be found not in the regional legislation but in the federal act of Germany [9]. In the German Renewable Energy Sources Act, the term "renewable energy source" covers "hydropower including wave, tidal, salinity gradient and marine current energy, wind energy, solar radiation energy, geothermal energy and energy from biomass including biogas, biomethane, landfill gas and sewage treatment gas, and from the biologically degradable part of waste from households and industry".

3.4. Terms

René Descartes argued that much controversy could be avoided if there was agreement about the meaning of words. Despite the fact that energetics is an exact science, many terms have definitions that allow for certain different interpretations. This can both cause inconvenience and contain the potential for deliberate abuse. An example of this inconvenience is found in [34], where the change in the legal definition of "small RES power plant" from 50 kW–500 kW to 50 kW–1 MW in Poland on 30 October 2021 received the following comment: "Some difficulties were encountered during the research, especially related to amendments of legal definitions of the facilities investigated in Poland, and the impossibility of comparing results in subsequent years." The use of external sources such as dictionaries, professional literature or established practice seems, at best, a compromise solution. Regulatory legal acts establishing preferential regimes must clearly indicate who can apply for them and in what cases, which means that any terms that may cause disagreement must either be defined in the same act or in a document that is developed with the participation of the same group of lawyers that works to regulate the fundamental law.

A situation may also arise when the terms are already defined at the level of federal legislation. If their list is exhaustive and covers all the needs of the regional law, it is enough to get by with a blanket norm, but if additional definitions of terms need to be approved, it is advisable not to combine a reference to a federal act and several new definitions but to duplicate all the necessary definitions, supplementing them with new ones.

If the definitions of terms are included in a separate regulatory legal act, with the legal force of which and the authority required to amend them being lower than that of the main regional law regulating renewable energy, an incompletely correct situation arises. The law that regulates renewable energy in a region becomes partially determined by the content of a regulatory legal act of lesser legal force.

There also are two main approaches to defining the terms directly in the laws in which they are used. The first one involves listing all terms with their definition in a separate article, usually one of the first in a regulatory legal act. The second approach is to expand the definitions of terms as they appear in the text. The choice of approach primarily depends on the legal technique adopted in the country and in the region, but in the aspect of the considered topic the second approach has certain disadvantages. When amending a normative legal act, it would have to be taken into account whether the new text uses a term the definition of which is disclosed only in subsequent articles and whether it is necessary to make corresponding changes.

When forming a terminological dictionary, it should be additionally checked for each term whether it is possibly given a differing definition in other regional or federal regulatory legal acts. If some terms are already defined and not in a context in which it is convenient for the purposes of the renewable energy law, it is important to determine the legal force of the act defining them. If it is not higher in legal force, a different definition of the term can be introduced by adding the necessary clarifications about the context of use without concern of possible abuse. Otherwise, it is worth checking whether the term itself can be adjusted by adding a clarifying element to it which would narrow the use specifically to the scope of renewable energy power plants.

To develop a terminological dictionary, it is advisable to form a working group that includes lawyers and engineers—specialists in the field of renewable energy.

3.5. Principles

Renewable energy law is not a full-fledged branch of law, and even as a sub-branch of energy law it is not singled out by all researchers of legal systems. Therefore, renewable energy law does not have a developed generally accepted traditional system of principles that could work even without their direct consolidation in normative legal acts. Consolidating the fundamental principles of operation is not a mandatory element of every regional law, but since a normative legal act on renewable energy is exceptionally socially, economically and environmentally significant, the formulation of principles in it seems appropriate. The system of principles allows the legislator to check whether further lawmaking activities are being carried out in the correct direction and makes it easier for law enforcers and judicial authorities to interpret other norms.

Before formulating the principles of regional legal regulation of renewable energy, it is necessary to refer to both federal legislation and regional legislation determining broader areas of activity.

If the principles are formulated in federal law, there is no direct need to introduce them by regional legislation. But they can be duplicated or made use of with a blanket norm. It is worth paying attention to the fact that the sphere of relations relating to renewable energy is also covered by energy law; in addition, it is worth checking the presence of principles in the legislation on energy saving or on energy efficiency.

Based on the analysis of the legislation of the component states of the Russian Federation and some component states of other federations, such as the USA and the Federal Republic of Germany, it is possible to form a synthetic list of principles that would be reasonable to use as the basis for regional legal regulation of renewable energy power plants. This list is not mandatory and is only advisory in nature; it can be modified depending on the characteristics of both the federation and each of its component states, and the list was intended to be as universal as possible.

The principles in the list are arranged hierarchically in order of importance but, depending on the priorities of the federation, the position of individual principles in the list may shift; the current version of the list is relevant for the Russian Federation and for countries with a similar approach to the legal regulation of energy.

The first principle is to ensure the energy security of the federation as a whole. In most countries, the interests of the region in such an industry as power supply cannot be placed above the interests of the entire country, and if some regional initiatives, for example, the decommissioning of large power plants based on traditional energy sources, create a real threat to the energy security of the entire federation, even if the distribution of subjects of jurisdiction allows the region to carry this out, such actions should not be carried out without creating joint working groups with the federal center in order to minimize negative consequences.

The second principle is to ensure the uninterrupted and reliable operation of energy facilities in the region itself. For entrepreneurs or other small- and medium-sized consumers, a balance between the stability of energy supply and its environmental friendliness and economic feasibility is a disputable matter, but the vital social infrastructure of the region must reliably and uninterruptedly be provided with heat and electricity. Therefore, any initiatives to introduce distributed generation or renewable energy sources for their energy supply can only be considered if the condition of maintaining the previous level of reliability of the operation of energy supply facilities is met.

For example, in Texas, USA, after a devastating snowstorm that left millions of people without power, there was a rise in voices advocating for a reduction in the pace of development of renewable energy in favor of more stable gas power plants [35], although the advantages of such power plants in the conditions under consideration are debatable. This region also provides examples of tools aimed at ensuring a stable energy supply; in Texas [36], more money would be paid to companies that generate energy that will be available when grid conditions are tight and, on the contrary, penalties are established for those who are not ready to produce energy in a period of high demand, which was supposed to stimulate owners of power plants based on renewable energy sources to supply them with additional accumulators.

The third principle is maintaining a balance of interests between generating companies and consumers. The transition to distributed generation and independent energy supply, on the one hand, should be simplified as much as possible for the consumer, and on the other hand, it should not create critical risks for generating companies in the region. Capital investments in energy infrastructure, including linear facilities, can have extended payback periods, and a systematic occurrence of a significant number of grid-connected consumers deciding to go off-grid can cause heavy losses to generating companies; therefore, it is necessary to anticipatorily consider compensation measures that would soften this process and prevent risks for those subscribers who would decide not to switch to distributed generation and to remain connected to main power grids. Wyoming, USA, for example, has attempted to impose a one-year moratorium on the construction of new renewable energy power plants to protect the state's traditional coal-fired power plants and to keep energy rates from rising for ratepayers [37].

The fourth principle is to ensure the environmental safety of power generation and to reduce the level of negative impact on the environment. Federations and regions can decide to move this principle to the top of the list since it is of greatest importance from the point of view of long-term planning and sustainable development of the region for generations to come. The reduction of negative environmental impact caused by traditional energy sources is the main motivation for the transition to renewable energy, valid even for those regions that do not have a direct economic need for it. At the same time, the negative impact may not be limited to the territory of the state itself. Thus, California, USA, declares a responsibility to take steps to ensure that the state's transition to carbon-free energy does not lead to an increase in greenhouse gas emissions in the rest of the country [38].

The next principle is relevant only for countries that seek to increase their energy autonomy and is to ensure the technological independence of the energy industry. Full energy security is unattainable without the ability to support the operation of power plants by means of local industry. To accomplish this, it is necessary to create economic incentives for the development of the production of main and auxiliary generating equipment.

The sixth principle is to ensure the availability of information on the composition and implementation of measures to realize state policy in the field of regulation of energy installations based on the use of renewable energy sources. Regional government programs, preferential regimes, subsidies and competitions gain maximum effectiveness as a tool for increasing the share of renewable energy in the region only if information about them is available to all interested parties. Governor J.B. Pritzker of Illinois, USA, listed "Strengthen utility company transparency and ethics requirements" first among the principles that represent guideposts for crafting a legislative proposal that puts consumers and climate first [39]. Approaches to providing information will be discussed in a separate section of the article.

The last principle is the recognition of the activities of legal entities and individuals related to the production of energy by renewable energy power plants as environmentally friendly activities. This approach allows the region to assign the appropriate incentives and benefits to organizations that promote the introduction of renewable energy by manufacturing generating equipment, by installing and servicing plants, by providing technical, economic or legal support for their operation and so on.

In addition to what is discussed above, there are also less common but also promising principles that are recommended to be used. For example, in California, USA, one of the principles is to influence policies in other sectors of the economy so that they promote the development of renewable energy [38]. In Minnesota, USA, there are separate provisions "ensuring that all Minnesotans share the benefits of clean and renewable energy and the opportunity to participate fully in the clean economy" and "the provision of affordable electric service to Minnesotans, particularly to low-income consumers" [40].

3.6. Energy Accounting

Fuel and energy resources accounting is a system of measures and technical means the main purpose of which is to obtain information on the amount of extracted, produced, processed, transported, stored and consumed fuel and energy resources.

Organization of fuel and energy resources accounting is the legal, organizational and technical support for commercial and technical accounting of fuel and energy resources.

Accounting should be carried out at all technological stages and should not depend on the scale of production and consumption. The organization of accounting relates to issues of standardization and metrology and is usually regulated in federations at the federal level and does not need to be enshrined in regional legislation. The corresponding section of the regional act contains norms that refer to federal acts establishing accounting rules, duplication of federal norms and the establishment of a body of the executive branch responsible for organizational issues of resource accounting in the region.

As a result, it can be concluded that for federations in which accounting falls under the competence of the federal authorities, the corresponding section is not mandatory since its content can be placed in other sections or in other regulatory legal acts without violation of the internal logic of legal acts.

If the component states themselves determine the features of renewable energy resources accounting, it is necessary to strive for maximum unification with other regions of the federation, focusing on the uniformity of measurements using standardized instrumentation. This is also necessary for compliance with the principle of ensuring the energy security of the state, since without proper organization of accounting the effectiveness of any forecasting and assessment of the risks facing the country are reduced, and for communication on energy issues between different component states of the federation.

3.7. Regulatory Bodies

The next step should be to enshrine the powers in the field of legal regulation of renewable energy power plants for all federal and regional regulatory bodies directly involved in the process.

Prior to listing the powers of bodies in the field of regulation of renewable energy in the law, it is necessary to determine which bodies in the region actually have the corresponding powers. This will certainly include the legislative body of the region since the very power to adopt the normative legal acts regulating the legal status of renewable energy power plants will already suffice. Next, it should be found whether the head of the region and the head of executive branch of the region are vested with the appropriate powers (if the head of the region is also the head of executive branch, the main executive body subordinate to him or her should be checked). Then, it should be checked whether the region has a regulatory body whose core competence includes resolving issues in the field of renewable energy. Then, based on the previously drafted system of legal acts of the region regulating renewable energy power plants, all the remaining bodies of regional government that have separate powers in the considered field should be found. At the last step, it is necessary to check whether local self-governments have the appropriate powers.

Enshrinement of all the powers of each body involved in the process of regulating renewable energy in one regulatory legal act has several advantages and one disadvantage. The disadvantage is that some of these norms will duplicate the norms enshrined in other normative legal acts (for example, in regional laws on bodies of regional government), and the legislator will need to ensure their timely synchronization in order to avoid conflicts. The advantage for the legislator is that legal regulation organized in this way is easier to improve and maintain. Such consolidation protects against assignment of the same power simultaneously to several bodies and prevents both the risk of overburdening one of the bodies with powers and responsibilities and the danger of involving an excessive number of bodies in the regulation of simple relations, which overcomplicates the bureaucratic part of regulation. In addition, enshrining the powers of all bodies in one legal act also simplifies legal regulation.

For consumers, the advantages are the easier determination of the authority that needs to be contacted to solve a specific problem and the simplification of the composition of a step-by-step plan for renewable energy transition of their enterprise.

As an analysis of the current regional practice of legal regulation of renewable energy shows, one of the most important conditions for increasing the efficiency of regulation is the determination of the regulatory body responsible for renewable energy in the region. In most cases, this is a body in the executive branch of the region, such as the regional Ministry of Energy in which the corresponding department has been formed. The existence of a regulatory body, the main competency of which will include the introduction of renewable energy into the energy structure of the region and a constant reporting indicator of which will be the effectiveness of this implementation, simplifies interaction between the bodies of the regional government, the local self-government and the consumers. The regulatory body shall monitor the energy supply and demand and their structure in the state and shall compose the recommendations for legislation and non-government initiatives that will cause the necessary institutional and regulatory changes that would aid in achieving the planned objectives of energy development in a manner that balances the interests of involved bodies from the economy, environment and culture fields.

If the legislation of the country and the region allows, the regulatory body must have the right of legislative initiative in the field of its jurisdiction and must be able to exercise departmental control over the activities of other bodies and officials in the field within the limits permitted by the general rules for similar bodies in the country acting in other fields. To operate most effectively, the regulatory body must set targets for the development of renewable energy in the region and must calculate the costs of innovation, which is the ratio of actually obtained results to the funds spent to achieve them. These targets may belong to one of the following but are not limited to: further introduction of renewable and alternative energy to energy markets, increasing the number of research and development and generating companies that work with clean energy technologies, adopting incentives for commission and retrofitting of the existing generating facilities operating on alternative and renewable resources. The absence of a directly designated regulatory body leads to a dilution of authority and, most importantly, the dilution of responsibility. The need to coordinate actions between a number of elements formally at the same level of the system of bodies of regional government without a clearly defined leading one delays the bureaucracy, hinders the response to challenges and threats and confuses the consumer in their search for the body they need to contact to resolve their issue. At the same time, in order for the regulatory body to perform its functions and be obliged to perform them effectively, it is necessary to outline both its competence and responsibility, including the forms of reporting on the work performed, in regional legislation as specifically and unambiguously as possible.

For example, in California, USA, the regulator uses programs to implement energy policy and reports to the state body of the legislative branch [38]. The report includes an overview of current policies, including technologies used; forecasts; conclusions on achievements in policy implementation; assessment of financial costs and benefits; barriers to energy policy implementation; alternative scenarios for the development of renewable energy in the region. This report structure can be used as a model of an annual report in the responsibility of the regulatory body.

The regulatory body may not be selected from pre-existing bodies of the regional government or be newly organized for this purpose by regional authorities but may be established at the federal level and become uniform for every component state of the country. For example, in India there are State Nodal Agencies which are appointed by the federal Ministry of New and Renewable Energy [41].

The allocation of a regulatory body in the field of legal regulation of renewable energy power plants does not pose any additional risks for democratic procedures, since the practice of allocating regulatory bodies to individual fields at the regional level has been repeatedly worked out, for example, in healthcare, tourism and education.

The powers of the legislative body of the region in most cases include the adoption of laws and other regulatory legal acts in the field of regulation of renewable energy, including those establishing, within acceptable limits, liability for violations in this area.

If regional parliamentary control is allowed in the country, the powers may include monitoring the implementation of acts adopted by the legislative body in the field of regulation of renewable energy, as well as monitoring the implementation of programs of regional government if such programs exist.

In addition, if regional parliaments participate in the formation of regional budgets, the powers of allocating funds for the regional budget for the events aimed to increase the share of renewable energy in regional generation should be listed.

The powers of the highest body of the regional executive branch depend, first of all, on what degree of freedom is allocated to the regulatory body. Thus, the development, approval and implementation of regional government-funded programs for the development of renewable energy can be attributed to the powers of the highest body of the regional executive branch, the powers of the regulatory body or distributed between them, optionally, with the involvement of the legislative body.

In some of the analyzed regions the powers include the designation of a regulatory body in the field of use of renewable energy sources, but it seems more appropriate for it to be determined at the level of a regional law rather than by an act of an executive authority.

In any case, the highest body of the regional executive branch will retain powers related to the implementation of state policy on the development of renewable energy.

Depending on the nature and features of the separation of powers and the system of checks and balances in the region, its head may receive any of the powers discussed above except for the right to pass laws regulating renewable energy. The analysis did not show any examples of unique competency that the head of the region may possess; moreover, some regulatory legal acts do not assign to this person any powers in the field of regulation of renewable energy.

Depending on the established distribution of subjects of competence in the component state, the powers of bodies of local self-governments can either be limited to providing assistance to individuals and organizations in manufacturing and the installation of the equipment for the use of renewable energy sources or fully duplicating the powers of regional bodies at the local level.

The answer to the question of legal regulation of international cooperation in the field of renewable energy should begin with the clarification of whether the participation of individual component states in international cooperation is in principle allowed. If such a possibility exists, the regional law must strictly regulate a specific list of questions on which it can be formed and principles on the basis of which it should occur. This is important for the fulfillment of the priority principle of the energy security of the federation. The list of specific forms of international cooperation based on the developed principles can be formulated as closed if it is approved by an act inferior in legal force to the laws of the region which can be amended easily and quickly so as not to miss the prospects opening up for the region due to bureaucratic delays associated with amending the regional law. If the list of forms of cooperation is established precisely at the level of the regional law, it is better to leave it open since, in compliance with the principles established by law, if the cooperation follows the framework of the permitted questions on which cooperation can be made, any of its forms should not pose a danger. It is possible to maintain such a list in reverse, according to the principle "everything is permitted that is not directly prohibited by law".

3.8. Methods for Implementing Information Support

In general, all information support can be divided into informing about the regional regulation of renewable energy power plants and advocating for the introduction of renewable energy. Information support in the field of use of renewable energy sources should be organized by the regulatory body, but the events can be implemented by a variety of entities. For example, in addition to the regulatory body, informing about the regulation can be carried out by the legislative body of the region or its head, and in addition to public authorities, any interested parties can advocate for the introduction of renewable energy.

The principle of ensuring the availability of information on the planning and implementation of measures to implement state policy in the field of regulation of renewable energy power plants can be implemented without government participation. Taking into account modern opportunities for access to information, with a sufficient level of civic consciousness in the regions involved and with the active participation of the media, all interested consumers will receive all the information they need. But in our opinion, the responsibilities of the legislator should include establishing guarantees for the implementation of each of the declared principles. Therefore, it is necessary to establish methods for implementing official information support and incentives for the implementation of non-official information support and to separately regulate the creation and maintenance of the functionality of the infrastructure necessary for information support.

The analysis of regional legal regulation allowed for the formation of a base of recommended methods of information support which are practically independent of the political and legal conditions in a particular federation and its component states.

Regional programs for the introduction of renewable energy sources and projects for the creation of large-scale renewable energy power plants must be submitted to public hearings. In many federations, this is a mandatory procedure, and in this case, it is only necessary to ensure sufficient publicity for the opportunity to take part in the hearings. In regions of those countries that do not establish such a duty, it should not be introduced for energy installations, since this, on the contrary, has the potential to become an additional obstacle to their implementation. But a public discussion of the regional program with the participation of energy workers, environmentalists and representatives of interested groups would allow for identifying possible shortcomings in the regional program, would increase its legitimacy after adoption and, importantly in the discussed context, would serve the purposes of information support. The presence of a permanent body that is engaged in public control in the field of renewable energy is an additional advantage. The example of such body is the Community Solar program (CSCNM) [42] in New Mexico, USA, which works in parallel with the New Mexico Public Regulation Commission and Renewable Energy in New Mexico [43], reviewing community solar initiatives and developing recommendations for their implementation.

Another almost obligatory element of official information support is the provision of information on the use of renewable energy sources upon the direct request of consumers. Generalized experience shows that the universal principles of forming sustainable feedback between the government body providing the service and the consumer of the service are at work here. The most effective measures are hotlines organized by the regulatory body, online consultations including the use of bots to answer simple questions, the preparation of a publicly available F.A.Q. and regular meetings of authorized employees with interested consumers. An example of a very simple but effective method is a clear and concise document published in Colorado, USA, containing general information and links to all renewable energy support programs available in the state [44].

The next element depends on the features of regulation of work with information and on the degree of digitalization of data in a federation. The regulator could be charged with establishing and maintaining a regional renewable energy information system. This could be one of the building blocks of a larger regional information system in the field of energy saving and energy efficiency. In addition to information support, such a system allows consolidating information about the features of the distribution of energy installations across the region, highlighting weaknesses and points of growth.

Official advocacy of renewable energy can be achieved through a variety of tools. One of them is the preparation of demonstration projects for the use of renewable energy sources. Demonstration projects can be either open to the public through specially created demo stands that perform only educational tasks or projects modeling the operating features of actual installations demonstrated during special events.

Another method is to organize exhibitions of equipment and technologies related to renewable energy sources. Regional authorities can hold such exhibitions on their own, in collaboration with major participants in the energy market, or provide information and organizational support to exhibitions organized by external participants.

If there are sufficient resources, the regulatory body can organize media dissemination of thematic awareness-raising programs about events and methods of transition to renewable energy sources, about achievements in this field both among producers and consumers of the region and the entire federation and about scientific discoveries and breakthroughs at the world level. In the same way that information can be disseminated about the environmental and economic potential of the transition to renewable energy, the incentives and benefits will be provided to consumers and anyone involved in the production of energy by renewable energy power plants. These individuals should also include those whose activities are aimed at popularizing renewable energy and bring measurable results.

3.9. Regional Programs

Regional programs have proven to be one of the most effective tools for regulating the development of renewable energy at the regional level in the Russian Federation. A regional program is an act inferior in legal force to the laws of the region which is adopted by the regulatory body that establishes target efficiency indicators for the introduction of renewable energy into the regional energy system, a list of events that must be carried out to achieve these indicators, the timeframe within which they must be carried out and the form of reporting.

At the same time, there is often no direct need to adopt a separate regional program aimed specifically at the introduction of renewable energy power plants. Depending on what principles and goals are prioritized in the transition to renewable energy, this may be a specialized subprogram within broader programs for energy conservation, energy efficiency, carbon neutrality or energy security.

In order for regional programs to work as an effective tool, they must meet a number of requirements. In case of partial or complete discrepancy, they can either continue to produce a beneficial effect or create space for imitation of activities or the development of corruption.

Regional programs must be adopted by the regulatory body or the highest body of the regional executive branch. If the regional program is adopted by the regulatory body, it must be approved by the body of the legislative branch or the highest body of the regional executive branch that would check for compliance with the principles of regulation of renewable energy stated in the regional legislation, with the goals set for the regulatory body in this area and with the regional resources.

Regional programs should be submitted for professional and public audits, the results of which should be mandatorily available for those representatives of the regional authorities who will make decisions on the approval of the program. Regional programs should not be adopted for periods exceeding the term of office of the bodies approving them. If the regional program should include activities that are impossible or impractical to implement within such a time frame, they should be divided into logical stages, each of which should not exceed the duration of the regional program. Any changes to the regional program related to a reduction in target indicators must be made through its re-approval, accompanied by an explanatory document outlining the reasons for such a change, and a new version must also undergo a professional audit.

To establish the procedure for the adoption of regional programs (or subprograms) in the field of renewable energy, the procedure for making changes to them and the procedure for conducting audits, as well as the procedure for accepting reports, it is necessary to adopt a number of rules either within the framework of the regional law on renewable energy or a separate regional law. In any case, this must be made in a regional act which should be higher in legal force than regional programs and higher than those acts that the body adopting the programs can issue.

It should be noted that the regional program does not necessarily have to be aimed only at global changes and the opening of new energy facilities. Some regions are not the most successful in introducing renewable energy into the energy system, yet small steps that move the region closer to increasing the share of renewable energy in its energy balance are also useful and valuable. In the Indian state of Madhya Pradesh, the main goals for solar energy development include hawkers and street vendors being encouraged to use solar lanterns; solar-powered street lighting would be encouraged too.

Regional programs can also be a tool for influencing the development of renewable energy in federations where legal regulation of energy is carried out primarily at the federal level and the component state does not adopt its own specialized laws. Regional programs are actively used in Germany: in Bavaria, it is the "Energy Storage Photovoltaic Program", and in Baden-Württemberg, it is the "Grid-Serving Photovoltaic Battery Energy Storage". Through this program, states allocate subsidies for the development of renewable energy, and individual cities subsidize the financing of new energy sources and require the construction of photo panels on new buildings [45].

Despite the fact that one of the main advantages of regional programs is their flexibility and the ability to quickly respond to new challenges and to introduce new technologies, it is advisable to establish a certain framework at the level of regional law to maintain stability. One of the issues that it is desirable to regulate in this way is the target indicators set by regional programs and the procedure for their calculation. Specific values of target indicators should be determined by the body adopting the program, but general directions should be given in the regional law. The most commonly used target indicators are the power generated by renewable energy power plants; the share of total power consumption covered by renewable energy and distributed generation; the volume of products shipped to renewable energy power plants; the capacity of newly commissioned renewable energy power plants; the amount of components produced for renewable energy facilities. Indicators related to the training of personnel and government employees are also targeted, and this could be the absolute or relative number of employees per period. Some programs add indicators related to information support for renewable energy, measured either by the work performed such as the minutes of screen time, the pages of text of materials promoting renewable energy or by audience coverage and statistical data on its impact (views, reactions, comments, shares and other parameters).

When drawing up a regional program, it is necessary to ensure that the list of activities aimed at increasing the share of renewable energy in the region does not include distantly related activities and purchases of equipment that can be used not only at renewable energy facilities. The construction and repair of linear facilities, even those associated with renewable energy power plants, should not constitute the main part of the activities within the regional program. Particular attention should be paid to setting tasks that do not require large capital investments: popularizing renewable energy, improving technical regulation, training of personnel, improving technical documentation for the construction and reconstruction of power plants and linear facilities and carrying out research work.

As the program progresses, it is advisable to require interim annual reports from performers which the regulatory body will collect and consolidate in an annual summary report which, in turn, will be presented to the highest regional body of executive or legislative branches and submitted for professional audit.

Due to the differences in the economic potential of the regions of different countries having a strong impact on the possibility of developing a fairly universal strategy, we deliberately avoided considering financial institutions for stimulating renewable energy, focusing in the methodology on those recommendations that can be used by a component state of any federation, regardless of the material resources at their disposal. An example of a detailed overview of regulatory incentives, including the possible economic incentives, can be found in a recent review [46].

3.10. Control and Supervision

Regulatory legal acts of the component states may duplicate the norms of federal legislation, and it is advisable to indicate in the regional law on renewable energy which federal bodies are responsible for control and supervision in this area. This will facilitate both the appeal of acts or actions of officials by energy producers and consumers and the regulatory consolidation of control and supervision at the regional level.

It is worth stating specifically in the regional law on renewable energy which bodies exercise control and supervision in this area at the regional level, even if this duplicates provisions from other regional regulatory legal acts. In the legal regulation of renewable energy, in addition to the obvious bodies involved in the control and supervision of energy, bodies performing, for example, environmental control may be involved, so it is better to directly consolidate the entire list of subjects of control in one act.

It is also advisable to establish in the act specific methods and forms of control and supervision within the industry. This will provide the necessary legal support, allowing better organization of activities of the authorities adopting new acts, energy producers, investors and other persons involved in the process of transition to renewable energy.

4. Conclusions

The issues most often covered by the regional legislation of federated states that successfully introduce renewable energy into their energy systems are the following: which energy sources are considered renewable; definition of the meanings of terms used in legal regulation; principles on which regional legal regulation is based; energy resources accounting in the subject; list of bodies implementing regional legal regulation; methods of information support; regulation of regional state programs for the development of renewable energy; control and supervision over bodies executing their powers in the field of renewable energy.

Based on the results of the analysis of the content of the regional acts, regulated issues can be divided into three groups, as shown in Figure 4.

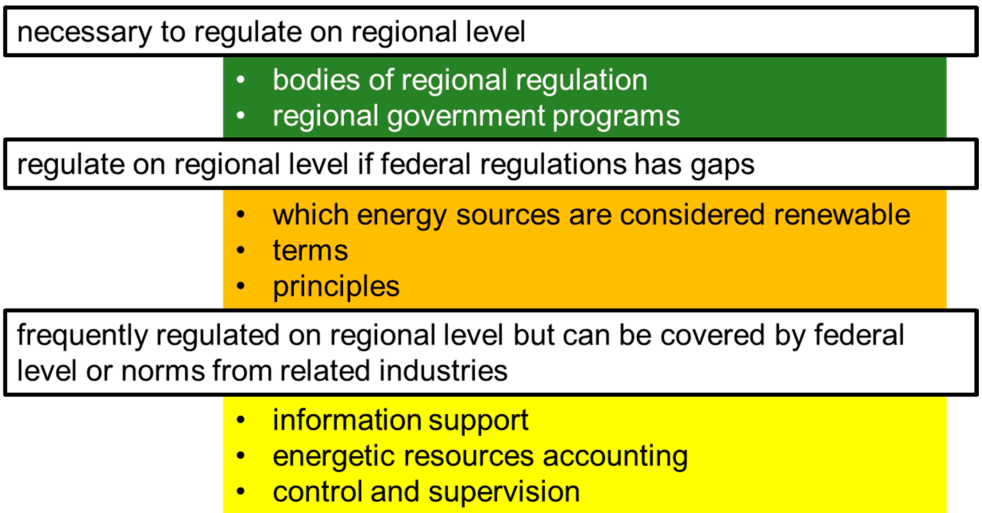

Figure 4. Necessity of the question of regulating renewable energy at the regional level.

The first group includes issues whose regulation in regional legislation is universally mandatory regardless of the nature of the relationship between the region and the federal center—this is a list of bodies that implement regional legal regulation and the regulation of regional state programs for the development of renewable energy.

The second group includes issues the settlement of which on the regional level is necessary in the absence or insufficiency of federal legal regulation, but in other cases such regional regulation may be absent itself or simply duplicate federal legislation. These are issues of determining which energy sources are considered as renewable, definition of the meaning of terms and definition of principles of legal regulation of renewable energy.

The third group includes issues that are often regulated within the framework of regional legislation on renewable energy but can be almost completely covered by federal legislation or regulations from related industries, so the resolving of these issues in regional regulation of renewable energy is of an auxiliary nature. These are issues of energy resources accounting, methods of information support and issues of control and supervision.

Regardless of the final internal structure of the document, the formation of a regional law on renewable energy should begin with the settlement of issues related to the first group. If a regional legislator, for whatever reason, does not have the competence to regulate the issues referred to in the first two groups, or these issues have already been fully regulated at the federal level to a sufficient extent and quality, the adoption of a specialized regional law may not be an optimal solution. In such a situation, the issues referred to in the third group can be regulated within the framework of regional programs, other sectoral laws and departmental acts.

Further research in this direction seems appropriate for focusing on revealing other components of the methodology of regional legal regulation of renewable energy such as determining the optimal set of principles and objectives of the regional law, defining the preferred competence of all the bodies involved in regulation and determining which specific economic and organizational mechanisms have the most positive impact on increasing the efficiency of renewable energy deployment at the regional level.

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Article

The Impact of the Rule of Law on Energy Policy in European Union Member States

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Abstract: Research pertaining to the dual-tier political system within the European Union (EU), specifically concerning the genesis and execution of EU policies, has garnered substantial scholarly attention. These inquiries delve into multifaceted dimensions, encompassing institutional dynamics, procedural intricacies, questions of legitimacy, and intricate relational dynamics entailing international diplomacy with other actors within the realm of international law. Nonetheless, a particularly intriguing and underexplored facet remains: the influence of member states' compliance with the rule of law on the implementation of EU policies, particularly within the realm of energy policy. This article aims to elucidate the nexus between the realization of energy policy objectives in EU member states and fidelity to the rule of law. The conundrum of establishing a correlation between the indicators of environmentally sustainable energy policy and commitment to upholding the rule of law remains uncharted territory within the existing body of literature. Our analysis centers on a dataset derived from publicly accessible sources, reflecting data from the year 2020.

Keywords: energy system; rule of law; EU; green economy; brown economy; Poland

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1. Introduction

Research on the European Union's two-tier political system in the domain of EU policy creation and implementation has been the subject of numerous studies. These studies delve into various facets, including institutional dynamics, procedural intricacies, questions of legitimacy, and the complex web of international relations with other entities under international law [1–4].

Nonetheless, an intriguing and underexplored aspect pertains to the influence of member states' compliance with the rule of law—these being the national actors within the political system—in terms of the execution of EU policies that are the tangible outcomes of its operation. One such policy that warrants examination is the energy policy, as outlined in Article 194 of the Treaty on the Functioning of the European Union (TFEU) [5].

Publications posit that the European Union operates as a two-level political system [6,7]. This implies that it comprises two tiers of governance: the national level, represented by the governments of the EU member states, and the EU level, represented by EU institutions [8]. This dual-tier structure necessitates a dynamic of cooperation and competition, including interactions among member state governments at the EU level [9].

Decisions at this level manifest as EU law, enacted by the Council of the European Union (comprising ministers representing member states) and the European Parliament. Within the Council of the European Union, decisions emerge as a result of negotiations and compromises among member states, with the precondition that such decisions provide added value compared to actions at the national level. EU law, as per the treaty provisions and the jurisprudence of the European Court of Justice (CJEU), holds primacy over national law. The obligation to implement and uphold European law within EU member states is an inherent aspect of European integration, which primarily aims to establish a unified EU market and facilitate the free movement of goods, services, persons, and capital among member states. To achieve this, EU member states must adhere to common rules and standards, necessitating full compliance with European law. Hence, the European Union is characterized as a legal community [10].

In the context of public policy management, we can also identify a two-tier political system in Europe. National governments wield substantial influence over the formulation of EU policies and take into account the repercussions of these policies by conducting their own public initiatives at the national level based on the regulations they have jointly approved, adopted, and implemented at the EU level.

The rule of law stands as one of the foundational values of the Union, as enshrined in Article 2 of the Treaty on European Union (TEU). It also serves as a prerequisite for safeguarding all other fundamental values within the EU, including fundamental rights and democracy. Adherence to the rule of law is integral to the seamless operation of the EU. It underpins the effective application of EU law, facilitates the proper functioning of the internal market, fosters an environment conducive to investment, and nurtures mutual trust [11].

At its core, the rule of law finds its essence in the provision of effective judicial protection, hinging on the independence, credibility, and efficacy of national justice systems [12]. Democracy, as mandated by the Copenhagen criteria, is the requisite system for every EU member state. It entails the election of representatives in free and fair elections by citizens, who actively participate in the exercise of state and public authority. Civil rights, applicable to both citizens and non-citizens within a country, serve to constrain the exercise of power by the state.

While the rule of law, democracy, and civil rights each possess distinct meanings, they are mutually reinforcing and intrinsically interconnected. Civil rights, such as the active and passive right to vote or the right to a fair trial, represent tangible manifestations of democracy and the rule of law at their core. In the absence of the rule of law, which necessitates impartiality and independence within the judicial system, civil rights and checks on political power within a democracy remain hollow promises [13].

Unquestionably, the rule of law exerts a profound influence on the configuration and substance of policies created and implemented, particularly those arising from the obligations stipulated in normative acts. This domain extends to European policies, the directions of which emanate from the supranational level via the institutions of the EU's political system, in substantial collaboration with its member states.

European policies, encompassing those formulated within the framework of the Energy Union [14], are not only implemented within member states but also wield substantial influence over national policies. This influence extends to the formulation and enactment of legislation and commitments undertaken by member state governments within the Council of the European Union at the EU level pertaining to the energy policies they enact across all member states. Observance and compliance with European law are not merely obligatory but also confer significant advantages upon EU member states. These shared regulations and standards establish a level playing field for both businesses and consumers within the unified EU market, thus fostering economic growth and heightened competitiveness [10]. However, this can only be realized when all national authorities uphold the rule of law within their respective domains.

The EU confronts a myriad of energy challenges, as delineated by Busch et al. [15] and Osička and Černoch [16]. These challenges encompass a broad spectrum, such as mounting import dependence, inadequate diversification, fluctuating and elevated energy prices, escalating global energy demand, the risks associated with the security of production and transit nations, the burgeoning perils of climate change, the imperative of decarbonization, sluggish progress in energy efficiency, the complications tied to the expanding deployment of renewable energy sources, the pressing need for enhanced transparency in energy markets, and the ongoing pursuit of greater integration and interconnection. Central to the EU's energy policy are a range of initiatives designed to establish a cohesive energy market and ensure energy supply security, thereby fostering a stable energy sector [10,17].

EU energy policy is influenced by a range of factors [18,19], spanning diverse dimensions including political, legal, economic, technological, and social aspects. The prevailing approach to sustainable development postulates that (eco)energy constitutes, and will continue to constitute, the cornerstone of socio-economic progress [20]. Sustainable energy [21,22] serves as the solution to humanity's energy demands. Eco-energy encompasses energy sources that can be harnessed without being depleted or requiring renewal [23]. Within this context, it is imperative to consider the concepts of the green economy and post-growth economy [24,25]. The green economy is epitomized by the "FIT for 55" initiative in the EU [26].

The core elements of the EU's current energy policy agenda revolve around addressing energy security concerns and aligning energy targets with climate objectives [27]:

- Reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990's levels.
- Enhancing energy efficiency by 32.5%.
- Elevating the share of renewable energy in the overall energy mix to 42.5%, with an ultimate target of 45%.
- Lowering primary and final energy consumption by the EU by 11.7% in comparison to the 2020 projections by 2030, translating to 40.5% and 38%, respectively, versus 2007 projections.
- Expanding interconnections to encompass at least 15% of EU electricity systems.
- Achieving net greenhouse gas emissions of zero by 2050.

Nonetheless, the extent to which the EU has implemented these green indicators in its policies exhibits variations. The prevailing geopolitical situation and its economic implications pose challenges. The conflict in Ukraine has led several EU countries to halt or slow down programs aimed at realizing a green economy. Consequently, certain EU nations continue to adhere to the principles of the brown economy, grounded in fossil fuels and non-renewable energy sources, without diligently implementing the regulations and obligations arising from their EU membership.

Given the context of our analysis, it becomes imperative to explore and scrutinize the interplay within EU countries between a foundational pillar of the EU—namely, the rule of law—and one of its paramount contemporary endeavors, that of energy policy. Within this framework, a series of fundamental inquiries should be posed:

- To what extent does the rule of law and the degree of adherence to it impact the realization of policies stemming from the imperative of enacting EU laws and delivering solutions that align with them, particularly within the realm of energy policy?
- How does the rule of law influence the degree to which energy policies prescribed at the EU level are effectively enacted?
- Which specific aspects of the rule of law exert the most significant influence on the efficacy of implementing EU regulations and fulfilling commitments to fellow member states in the domain of energy policy?
- Can a lower level of adherence to the rule of law in a member state contribute to setbacks or distortions in the pursuit of energy policy objectives by individual states within the broader context of the EU's political system?

The main goal of the article is to determine the impact of the rule of law on the effectiveness of implementing the objectives of the European Union's energy policy. Specific objectives include:

- Demonstrating the relationship between the rule of law and the level of implementation of energy policy in EU member states,
- Highlighting the key components of the rule of law in the context of the efficiency of energy policy implementation,

- Determining the level of influence of these components on the progress of implemented energy policy,
- Raising awareness of the importance of law enforcement for the coherence of the jointly adopted policy, including the interconnection of these two areas to achieve the goals set by the EU,
- Identifying countries that act as "drivers" in implementing energy policy and those acting as "spoilers" deviating from adopted commitments to a "side track",
- Presenting selected conditions of the state of the rule of law in relation to the implementation of EU energy policy commitments.

The hypothesis posited is that the state of the rule of law within EU member states has a direct impact on the implementation of energy policy, stemming from the commitments made within the European Union concerning its substance.

The issue of the correlation between the rule of law and energy policy is a pivotal facet that forms part of the broader widely debated discourse on the direction of the European Union in the face of evolving geopolitical, climatic, environmental, and economic changes [28–30]. In response to this challenge, the authors have undertaken an analysis focusing on the correlation between adherence to the rule of law in EU countries and green energy policy, with a particular emphasis on the Polish perspective. Remarkably, a comprehensive review of the existing literature revealed a scarcity of reports addressing this particular issue. Consequently, this article aims to bridge this knowledge gap.

Data analysis, according to the prepared methodology, was carried out in two stages. In the first stage, the analysis was carried out using a strategic group map. It should be noted that this is not a typical method used in mapping states. It is used to analyze the competitiveness of businesses [31,32]. However, the authors used it in this article because of its research capabilities. In this context, it is a new application of a well-known method. Next, the correlation of key factors depicting energy policy with key factors defining the rule of law was analyzed. We did not find this type of analysis in the literature.

Contribution to knowledge development: The content of the article allows for the identification of correlations between the level of rule of law in European Union countries and the fulfillment of obligations arising from EU policies, in this case, energy policy. These analyses enable the identification of countries and governments that demonstrate loyalty to EU commitments, pursuing their national interest in line with European interests, as well as those prioritizing other interests over European ones. The conclusions from the analysis presented in the article have utilitarian value, providing scientific foundations for EU institutions to introduce disciplinary solutions for member states that violate or fail to adhere to the rule of law, harming the dynamics of its implementation in the Union as a whole.

2. Theoretical Approach

2.1. Rule of Law—Selected Aspects

Article 2 of the Treaty on European Union states that "The Union is founded on the values of respect for human dignity, freedom, democracy, equality, the rule of law, as well as respect for human rights, including the rights of persons belonging to minorities. These values are shared by the Member States in a society based on pluralism, non-discrimination, tolerance, justice, solidarity and equality between women and men" [33]. When we examine the European Union as a community of law within its two-tier political system, it becomes evident that the rule of law is founded on the premise that every member state, as well as other entities (including economic ones), shares and recognizes that all other member states and entities also uphold the same rule of law, guided by the principle of solidarity. In this framework, the rule of law aims to mitigate self-interest, both internally and externally (at the individual and national levels), and it safeguards the Union's order and values through universal adherence to the law.

In light of the above, the European Union is not merely a common market driven by legal considerations; it is also a community of values and principles centered on respect for and the observance of the rule of law. Thus, the market must be in complete alignment with these principles. It is within this context that the so-called rule of law mechanism should be comprehended. Mik [34] explains that "according to the rule of law, all public authorities must always act within the limits of the law, in accordance with the values of democracy and fundamental rights, and under the control of independent and impartial courts. The rule of law has a direct impact on the life of every citizen—it is a prerequisite for equality before the law and the protection of individual rights, the prevention of abuse of power by public authorities, and the accountability of authorities (. . .). The rule of law includes accountability for the way the law is made, fairness in its application and efficiency in its operation."

Taking the above into account, and guided by the jurisprudence of the CJEU, the European Court of Human Rights (ECHR), and the documents of the European Commission and the Venice Commission, it becomes possible to define the basic set of elements comprising the concept of the rule of law. Thus, it is based on the following (A new EU framework to strengthen the rule of law), available at: https://eur-lex.europa.eu/legal-content/PL/TXT/HTML/?uri=CELEX:52014DC0158, (accessed on 6 October 2023):

1. Legality—meaning a transparent, accountable, democratic, and pluralistic process of passing laws,
2. Legal certainty—which requires that regulations be clear and predictable and, as a rule, cannot be amended retrospectively,
3. The prohibition of arbitrariness in executive action—which requires that the interference of public authorities in the field of the private activity of an individual or legal entity has a legal basis and is justified by reasons set forth in the law,
4. Independent and effective judicial review—including review of respect for fundamental rights and an independent and impartial judiciary respecting the principle of the separation of powers,
5. Equality before the law—Annex I to the communication.

All member states are both legally and politically obliged to uphold the rule of law, a requirement that arises not only from Article 2 but also from Article 7 of the TEU, which has been ratified by all EU member states. Article 7 provides a mechanism to hold member states accountable when they fail to meet their obligations. The essential components of the rule of law are comprehensively defined and developed within various binding EU laws, including the recently enacted Regulation (EU, Euratom) 2020/2092 of the European Parliament and the Council, dated 16 December 2020, which establishes a general system of conditionality to safeguard the Union's budget [35]. The Council of the European Union, comprising ministers from all member states, adopted this regulation through a standard procedure in conjunction with the European Parliament, whose members are elected by citizens from all member states. These elements are also incorporated into the constitutions and laws of all member states, the European Convention on Human Rights, and the UN human rights treaties, all of which have been ratified by every EU member state [13].

It is important to note that the rule of law is not an concept externally imposed on EU member states. Rather, these states themselves have defined its fundamental elements at the supranational level of the EU for implementation within their national laws. At this level, these elements were subject to negotiation among these states and adopted unanimously. In the context of the EU's two-tier political system, it is the EU legislator, consisting of the European Parliament and the Council of the EU, which identifies elements of the rule of law particularly relevant to specific policy areas. The Court of Justice of the European Union and the European Court of Human Rights provide clarification on how the various elements of the rule of law are to be understood within the context of specific cases. In turn, national courts are bound by the judgments of the CJEU when applying or interpreting the Union's rule of law. The CJEU, in its decision-making process, also takes into account judgments from the ECHR concerning the essential elements of the rule of law [13].

The European Union is not just a common market; as previously mentioned, it also stands as a community of values and a source of rights for its citizens, as outlined in Article 2 of the Treaty on European Union (TEU). To fulfill this commitment to its citizens, all member states must maintain their status as functional liberal democracies that uphold the rule of law. Should the EU fail to ensure this, EU citizens working, residing, or investing in other member states cannot be confident that their rights, as enshrined in EU law, will be upheld. Problems with the rule of law can also erode the essential mutual trust required for legal cooperation between member states. For instance, if the independence of the judiciary is no longer guaranteed in one member state, the courts of another member state may face challenges in detaining individuals who commit serious crimes and extraditing them to the former. They may also encounter difficulties in recognizing divorce judgments issued in that country. These issues have a direct impact on the lives of EU citizens [13]. The respect for the rule of law is not only vital for the Union's citizens but also for economic initiatives; innovation; investment; economic, social, and territorial cohesion; and the proper functioning of the internal market. The internal market thrives when supported by a robust legal and institutional framework [36]. The rule of law, particularly the effective prosecution of breaches of the independence of the judiciary, is critical to economic activity. It paves the way for a secure, predictable, and equitable environment for contracting and resolving potential disputes. In cases where there are significant deficiencies in the rule of law within an EU member state, businesses based in the EU, as well as shareholders and customers, stand to lose. A competitive company cannot fully benefit from the EU internal market when procurement procedures are manipulated and there is a lack of investigation or prosecution of fraudulent practices. The export of goods can become problematic when contractual disputes cannot be resolved by an independent court [13].

Simultaneously, the EC Communication "A New EU Framework for Strengthening the Rule of Law" [36] stipulates that the precise content of principles and norms under the rule of law may vary at the national level. While the implementation of these principles may therefore differ from one member state to another, it is in agreement with the perspective presented in the literature that there is no need for unification and uniform practice of these principles across all states [37].

The European Rule of Law Mechanism is an annual procedure for a dialogue on the rule of law between the Commission, the Council, and the European Parliament, with the participation of member states, national parliaments, civil society, and other stakeholders. The core element of this new procedure is the rule of law report. The main goal of the rule of law mechanism is to stimulate inter-institutional cooperation and encourage all EU institutions to contribute according to their institutional roles. This goal aligns with the longstanding interests of both the European Parliament and the Council. The Commission also invites national parliaments and authorities to discuss the report and encourages the involvement of other stakeholders at the national and EU levels. The mechanism prepares a report on the rule of law each year and conducts preparatory work with member states. The report serves as the basis for discussion in the EU and aims to prevent the emergence or exacerbation of problems. Identifying issues as early as possible with mutual support from the Commission, other member states, and stakeholders, including the Council of Europe and the Venice Commission, can assist member states in finding solutions to uphold and protect the rule of law [38].

Taking the above into account, in July 2022, the European Commission published the next edition of its cyclical "Rule of Law report" [39]. This document analyzes the state of the rule of law in each EU member state. The European Commission's active engagement in the rule of law is grounded in Article 2 of the TEU, which lists the rule of law as one of the fundamental values upon which the entire EU is built.

Concerning the rule of law, and in response to clear violations by some member states, the European Union initiated practical enforcement. This process took the form of, for example, a regulation made by the European Parliament and of the Council on the general system of conditionality for the protection of the Union budget. It identifies violations of the rule of law as (1) jeopardizing the independence of the judiciary; (2) failing to prevent arbitrary or unlawful decisions by public bodies, including law enforcement agencies, failing to rectify such decisions or impose penalties on them, withholding financial and human resources affecting the proper functioning of such bodies, or failing to ensure a situation devoid of conflicts of interest; (3) limiting the availability and effectiveness of legal remedies, including due to restrictive procedural rules and the failure to enforce judgments, effectively prosecute law violations, file and support charges in connection with such violations, or impose penalties related to these violations [40]. In this legislation, the rule of law aspect relates to financial matters. Appropriate measures are taken when a violation of the rule of law in a member state is identified. In practice, this means affecting or seriously risking affecting—in a sufficiently direct manner—the sound financial management of the EU (member state) budget or the protection of EU (member state) finances.

2.2. Energy Policy—Selected Aspects

The EU energy sector is defined by Article 194 of the Treaty on the Functioning of the European Union (TFEU) [17,41]: "Within the framework of the establishment or functioning of the internal market and taking into account the need to preserve and improve the environment, Union policy on energy shall aim, in a spirit of solidarity between Member States, (1) to ensure the functioning of the energy market; (2) to ensure security of energy supply in the Union; (3) to promote energy efficiency and energy saving and the development of new and renewable forms of energy; and (4) to promote the interconnection of energy networks." The TFEU identifies other elements affecting energy policy: security of supply (Article 122 TFEU); energy networks (Articles 170–172 TFEU); coal (Protocol No. 37 sets out the financial consequences of the expiration of the European Coal and Steel Community Treaty in 2002); nuclear energy (the Treaty establishing the European Atomic Energy Community provides the legal basis for most of the EU's nuclear activities); the internal market in electricity (Article 114 TFEU); and external energy policy (Articles 216–218 TFEU) [17]. According to the provisions made in the 2015 Energy Union, the five most important EU energy policy goals are [14]:

- Diversification of European energy sources, ensuring energy security through solidarity and cooperation among EU countries;
- Ensuring the functioning of a fully integrated internal energy market, allowing the free flow of energy in the EU through appropriate infrastructure and without technical or regulatory barriers;
- Improving energy efficiency and reducing dependence on energy imports, reducing emissions, and stimulating job creation and economic growth;
- Decarbonizing the economy and transitioning to a low-carbon economy in accordance with the Paris Agreement;
- Promoting research on low-carbon and clean energy technologies and prioritizing research and innovation to stimulate the energy transition and improve competitiveness.

The current European energy regulatory framework necessitates not only implementation but also involves a number of acts related to governance and electricity interconnection [42], the structure of the electricity market [43,44], emergency preparedness [45], energy efficiency [46,47], the energy performance of buildings [48,49], renewable energy [50,51], the structure of the gas market [52–55], the taxation of energy products [56,57], trans-European energy infrastructure [58], cooperation among energy regulators [59], and developments following the UK's withdrawal from the EU [60]. Under the current energy framework, EU member states are required to establish 10-year integrated national energy and climate plans for 2021–2030 [61], submit biennial progress reports, and develop coherent national long-term strategies [61] to achieve the agreed energy targets and the goals of the Paris Agreement. New markets for decarbonized gases, such as hydrogen, were introduced as part of the review, and new regulatory proposals were submitted in the transportation sector, including the Alternative Fuels Infrastructure Regulation [62], the ReFuelEU Aviation initiative [63], and the FuelEU Maritime initiative. A comprehensive EU "Fit for 55" package was published in 2021, with the original goal of aligning all energy and climate targets. This package included a review of all existing EU climate and energy acts.

Article 194 TFEU brings certain areas of energy policy under shared competence, signaling the transition to a common energy policy. Nevertheless, each member state retains the right "to determine the conditions for the use of its energy resources, the choice between different energy sources and the general structure of its energy supply" (Article 194(2) TFEU).

In summary, the European Union's energy policy, while addressing significant global challenges such as pollution, supply disruptions, the depletion of natural resources, the cost-intensiveness of new technologies, and biodiversity loss [64–66], is driving changes in the EU's socio-economic model through the aforementioned legislation [20]. Many economies, previously reliant on the brown economy model, are transitioning toward a green economy model [67,68]. In this new model, the primary objective of economic growth and development is to minimize the utilization of natural resources while enhancing the quality of life for the population [68]. These divergent approaches, with a specific focus on the energy sector, are illustrated in Table 1, organized according to the PEST method [69].

Table 1. Characteristics of the brown and green economy.

Category	Brown Economy	Green Economy
P:	Economy of energy supply	Self-sufficiency, energy security
P:	Relying on the cheapest energy sources	Diversification of energy sources
P:	Relying on traditional economic sectors	Change in economic structure
P:	Destruction of biodiversity	Protection of biodiversity
E:	Unlimited economic growth	Decoupling economic growth from natural resource consumption
E:	Infinity of resources	Limited resources
E:	Reliance on fossil fuels	Renewable energy sources
E:	Intensive consumption of natural resources	Energy efficiency
E:	Consolidation of the sector	Sector dispersion
S:	Global social inequality	Intergenerational and interregional justice
S:	Unlimited consumption (overconsumption)	Sustainable consumption
S:	Lack of accountability	Corporate social responsibility and ESG
S:	Weakening public confidence	Growing public confidence
T:	Greenhouse gas emissions	Clean production
T:	Modification of existing technologies	Advances in clean technology

Categories: political, economic, social, technological. Source: own study based on [20,69–72].

Expression of the implementation of each country's energy policy and their compliance with EU law is the submission of documents to the European Commission. These national plans outline how EU countries intend to address the five dimensions of the energy union: decarbonization; energy efficiency; energy security; the internal energy market; and research, innovation, and competitiveness.

2.3. Rule of Law and Energy Policy—Selected Relationships and Relations

The theme of the impact of the rule of law on economic initiatives, innovation, investment, and economic cohesion is closely related to issues concerning the implementation of energy policy across all EU countries. The energy sector differs fundamentally from other economic sectors.

First, it is a sector of paramount strategic importance. Without a stable energy supply, no country, economy, or society can function. This underscores the sector's pivotal role in each member country and in the EU.

Second, the energy sector is predominantly nationalized and monopolized. This characteristic inherently follows from its strategic nature and provides a pertinent context for examining the rule of law. The dominant role of the state and the existence of natural monopolies create an environment conducive to state intervention in this sector. Such intervention takes various forms, encompassing different aspects and implications:

In EU countries with a high regard for the rule of law, state intervention generally yields positive effects. Whether aimed at strengthening or reducing a country's dominant position in the energy sector, energy policy in such countries either fosters development or helps avert crises.

In EU countries with a lower regard for the rule of law, state intervention is more mixed. The energy sector may benefit from certain legal safeguards in some areas while facing challenges in others. The restriction, violation, or disregard of various aspects of the rule of law tends to be selective rather than systemic. In such cases, the state, whether due to negligence or deliberate non-compliance with elements of the rule of law in specific areas, deliberately influences certain aspects while reaping certain advantages.

In EU countries with a very low regard for the rule of law, state intervention tends to be systemic and has negative consequences. Systematic limitations; violations; disregard for legality and legal certainty; arbitrary decision-making in executive actions; impediments to effective judicial review; and the absence of equality before the law practically steer the energy sector toward underdevelopment. This keeps the sector entrenched in the brown economy, diminishing the standing and influence of a given EU member state within Europe and on the global stage.

Third, the energy sector is capital- and investment-intensive. The absence of guarantees regarding legal certainty, arbitrary decision-making by those in power, a lack of effective judicial review, and inequality before the law form a discouraging recipe for investors with capital. This practical effect results in a shortage of investment or a decrease in investment levels. Even when investments are made using domestic funds (the country's own), there remains a high likelihood of asymmetric economic situations that do not bode well for the energy sector.

Fourth, the energy sector is highly dependent on the environment and is a significant source of emissions. The failure to respect the rule of law leads to environmental harm, such as excessive emissions resulting from inadequate judicial oversight, the destruction of valuable resources due to arbitrary administrative decisions, and the elimination of individuals and entities engaged in environmental and resource protection caused by a lack of equality before the law.

The degree of respect for the rule of law within the energy sector in EU countries can be gauged using the WJP Rule of Law Index (more on this topic: https://worldjusticeproject.org/rule-of-law-index/about#howwemeasure (accessed on 23 June 2023)). developed by World Justice Project researchers, experts, practitioners and public opinion leaders. The WJP Rule of Law Index measures the state of implementation of selected elements of the rule of law.

The dimensions of the WJP Rule of Law Index, as described in Table 2, enable an analysis of the situation related to the implementation of the rule of law in individual EU countries. The areas of analysis, described by the indicators, include the Rule of Law Factors Constraints on Government Powers, Open Government, Fundamental Rights, Regulatory Enforcement, Regulatory Quality Index, Absence of Corruption, Order and Security, Civil

Justice, and Criminal Justice and form an overall score. The indicators representing the situation in the energy sector (Table 2) are referred to as energy policy factors, which include Contribution to Renewable Energy, Total Gross Available Energy, Eco-Innovation Scoreboard, Primary Energy Consumption, Final Energy Consumption, Effort Sharing Regulation, Level of Electricity Interconnectivity, and Energy Market Indicator. Both sets of indicators were selected based on expert knowledge, data availability, and the results of analyses carried out by the author's team in seminars and brainstorming sessions.

This article assumes that the selected WJP Rule of Law Index indicators, which assess the level of rule of law, enable the demonstration of the rule of law's impact on the energy policy of EU countries. Each indicator within the two groups characterizes a different aspect within the domains of the rule of law and energy policy. A thorough comparison of these indicators allows us to illustrate the interrelationships between these issues. Since these indicators are applicable to all EU countries, the analysis provides insights into the relationship between the rule of law and energy policy throughout the EU.

Table 2. Rule of Law Factors.

Lp.	Rule of Law Factors	Label	Definition
0	Overall Score	T	Average obtained from indicators 1–4, 6–9
1	Constraints on Government Powers	CGP	Measures the extent to which those who govern are bound by law. It comprises the means, both constitutional and institutional, by which the powers of the government and its officials and agents are limited and held accountable under the law. It also includes non-governmental checks on the government's power, such as a free and independent press.
2	Open Government	OG	Measures the openness of the government, defined by the extent to which a government shares information, empowers people with tools to hold it accountable, and fosters citizen participation in public policy deliberations. This factor measures whether basic laws and information on legal rights are publicized and evaluates the quality of information published by the government.
3	Fundamental Rights	FR	Recognizes that a system of positive law that fails to respect the core human rights established under international law is at best "rule by law" and does not deserve to be called a rule of law system. Since there are many other indices that address human rights, and because it would be impossible for the index to assess adherence to the full range of rights, this factor focuses on a relatively modest menu of rights that are firmly established under the United Nations Universal Declaration of Human Rights and are most closely related to rule of law concerns.
4	Regulatory Enforcement	RE	Measures the extent to which regulations are fairly and effectively implemented and enforced. Regulations, both legal and administrative, structure behaviors within and outside of the government. This factor does not assess which activities a government chooses to regulate nor does it consider how much regulation of a particular activity is appropriate. Rather, it examines how regulations are implemented and enforced.
5	Regulatory Quality Index	RG	The index of regulatory quality captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.
6	Absence of Corruption	AC	Measures the absence of corruption in government. The factor considers three forms of corruption: bribery, improper influence by public or private interests, and misappropriation of public funds or other resources. These three forms of corruption are examined with respect to government officers in the executive branch, the judiciary, the military, police, and the legislature.
7	Order and Security	OS	Measures how well a society ensures the security of persons and property. Security is one of the defining aspects of any rule of law society and is a fundamental function of the state. It is also a precondition for the realization of the rights and freedoms that the rule of law seeks to advance.

Table 2. *Cont.*

Lp.	Rule of Law Factors	Label	Definition
8	Civil Justice	CJ	It measures whether ordinary people can resolve their grievances peacefully and effectively through the civil justice system. It measures whether civil justice systems are accessible and affordable as well as free of discrimination, corruption, and improper influence by public officials. It examines whether court proceedings are conducted without unreasonable delays and whether decisions are enforced effectively. It also measures the accessibility, impartiality, and effectiveness of alternative dispute resolution mechanisms.
9	Criminal Justice	CJ	Evaluates a country's criminal justice system. An effective criminal justice system is a key aspect of the rule of law, as it constitutes the conventional mechanism to redress grievances and bring action against individuals for offenses against society. An assessment of the delivery of criminal justice should take into consideration the entire system, including the police, lawyers, prosecutors, judges, and prison officers.

Source: own study based on [73,74].

2.4. Data Sources and Transformation

To test the hypothesis, factors (variables) related to the rule of law (Table 2) were selected for analysis and compared with factors (variables) that influence energy policy (Table 3). Data on the rule of law were sourced from the World Justice Project® (WJP)'s databases [73]. The WJP Rule of Law Index® computes scores and rankings for 8 factors and 44 sub-factors, organized into eight categories. An additional ninth indicator, the Regulatory Quality Index, was included. Data for these factors were collected for all European Union countries in 2020. In cases where data for 2020 were unavailable, as for Cyprus, Ireland, Latvia, Lithuania, Luxembourg, Malta, and Slovakia, data from 2021 were used. This approach is justified by the observed long-term trends characteristic of these countries.

This article outlines the correlations for five factors (variables) and one aggregate linked to the rule of law, considering them the most influential factors affecting the implementation of energy policy (Table 2—lines 0–5). A comprehensive set of calculations for all variables, including those not discussed in detail in the article, can be found in the Data Repository "Correlation of the Rule of Law with Energy Policy" [75].

Data pertaining to the energy policy factors were sourced from various references: National Energy and Climate Plans—NECPs [76]—EUROSTAT (the nrg_bal_c database) [77], and "Eco-Innovation at the heart of European policies" [78]. European Commission documents were used as a reflection of European energy policy. NECPs were introduced as part of the Regulation on the Governance of the Energy Union and Climate Action (EU)2018/1999, which was adopted in 2019. Data were collected from multiple sources, and all the data used in the article are accessible in a publicly available database.

Since the data were collected from various sources, they were normalized to ensure their values fell within the range of 0.01 to 0.99. The normalization process was carried out as follows:

1. Data expressed as percentages remained unaltered and were recorded as a value after the decimal point.
2. Data not expressed in percentages were normalized using the following formula:

$$X' = \frac{X - Xmin}{Xmax - Xmin} \times (Vmax - Vmin) + Vmin \quad (1)$$

where:

X′—variable after normalization,
X—variable before normalization,
Xmin—the minimum value of the variable X before the transformation,
Xmax—the maximum value of the variable X before the transformation,

Vmin—the minimum value of the variable X′ after the transformation (0.01),
Vmax—the maximum value of the variable X′ after the transformation (0.99).

Table 3. Energy policy factors.

Lp	Energy Policy Factors	Label	Definition
1	Contribution to renewable energy	RE	Share of energy from renewable sources in gross final consumption of energy (FEC)
2	Total gross available energy	GAE	Means the overall supply of energy for all activities in the territory of the country. This also includes energy transformation (including generating electricity from combustible fuels), distribution losses, and the use of fossil fuel products for non-energy purposes.
3	Eco-Innovation Scoreboard	EcoIS	Measures the environmental innovation performance of EU member states on the basis of the 12 indicators included in the measurement framework.
4	Pimary energy consumption	PEC	Measures the total energy demand of a country. It covers the consumption of the energy sector itself, losses during the transformation (for example, from oil or gas into electricity) and distribution of energy, and the final consumption by end users. It excludes energy carriers used for non-energy purposes.
5	Final energy consumption	FEC	Is the total energy consumed by end users, such as households, industry, and agriculture. It is the energy which reaches the final consumer's door and excludes that which is used by the energy sector itself.
6	Effort Sharing Regulation	ESR	Binding target for greenhouse gas emission reductions compared to 2005 under the Effort Sharing Regulation.
7	Level of electricity interconnectivity	EI	Electricity interconnectivity refers to high-voltage cables connecting the electricity systems of neighboring countries. They enable excess power, such as that generated from wind and solar farms, to be traded and shared between countries. This ensures that renewable energy is not wasted and makes for a greener, more efficient power system.
8	Energy market indicator	EM	An energy market is a type of commodity market that deals with electricity, heat, and fuel products. It shows the concentration of energy production by major companies.

Source: own study based on [78–81].

Thanks to normalization, the variables accepted for analysis were normalized within a homogeneous range. In this way, the performance of the analysis will be of a comparative nature, and the graphs prepared will show relationships within the same area of variation of 0.01–0.99.

2.5. Methodological Assumptions

The research introduces a classification of individual EU countries by considering indicators related to the rule of law, the energy sector, and green and brown economy solutions. Table 4 outlines the four areas (O1, O2, O3, and O4) determined based on the arithmetic mean values of individual indicators (variables) associated with the rule of law and those related to the energy sector and green and brown economy solutions. These areas were defined systematically, aiming to address how a particular indicator contributes to upholding the rule of law or advancing the objectives of transitioning the energy sector with green economy solutions.

In the case of the rule of law, the division into areas O1, O2, O3, and O4 is based on the established development directions within the framework of European Union policy. The rule of law stands as one of the core values of the EU. Furthermore, it plays a critical role in the proper execution of energy policy within the EU and individual member states [79,82].

Table 4. Areas O1, O2, O3, and O4—definitions. For easier analysis, the different areas are color-coded.

O1	law-abiding above average and showing an indicator that realizes the green economy above average	**O2**	law-abiding above average and showing an indicator that realizes the brown economy below average
O3	law-abiding below average and showing an indicator that realizes the green economy above average	**O4**	law-abiding below average and exhibiting an indicator realizing the brown economy below average

Source: own study.

Areas O1, O2, O3, and O4 are applicable to both areas of analysis: the rule of law and energy. This means that within each of the four parts of Table 4, individual EU countries are categorized based on their alignment with the respective content area in accordance with the methodological proposal. Each EU country is placed in only one of the four areas: O1, O2, O3, or O4. According to the assumptions made, EU countries were categorized as having either a medium to high level of rule of law or a low to very low level of rule of law.

For each rule-of-law-related indicator, the arithmetic average was calculated, creating two analytical areas for each indicator:

- O1 and O2 for indicators with values above the arithmetic average
- O3 and O4 for indicators with values below the arithmetic average

EU countries with above-average indicator values (O1 and O2) were classified as those with medium and high levels of the rule of law, while EU countries with below-average indicator values (O3 and O4) were considered to have low and very low levels of the rule of law.

In the case of energy policy, the division into areas O1, O2, O3, and O4 is influenced by the adopted development direction within the framework of European Union policy, particularly the preference for the green economy. Deviating from the green direction (adopting the brown economy) effectively equates to practicing conventional economic policy within the energy sector.

Similarly, for energy-related indicators, the arithmetic average was calculated, forming two analytical areas for each indicator:

- O1 and O3 for indicators with values above the arithmetic average
- O2 and O4 for indicators with values below the arithmetic average

EU countries with above-average indicator values (O1 and O3) were categorized as those that moderately modernize the energy sector and favor green economy solutions. Meanwhile, EU countries with below-average indicator values (O2 and O4) were classified as those that moderately modernize the energy sector and lean toward brown economy solutions.

Following the methodology adopted, these extracted areas were overlaid onto each other to create a summary table in which each analyzed EU country falls into one of the areas: O1, O2, O3, or O4. The data used to derive areas O1, O2, O3, and O4 are documented in the Data Repository titled "Correlation of the Rule of Law with Energy Policy," which includes Tables 2, 4, 6, 8, 10, 12, 14, 16, 18, and 20 (Data Repository: A. Nowakowska-Krystman, R. Wisniewski: Correlation of the Rule of Law with Energy Policy [75]):

- Col. 1 describes variables related to the energy sector (green economy, brown economy),
- Col. 2 shows the range of values above and below average for "energy" variables,
- Col. 3 shows the EU countries classified into areas O1 and O2 and col. 5 areas O3 and O4,
- The designations of each area are included in cols. 4 and 6 on the corresponding lines,
- The headlines of cols. 3–6 record the calculated arithmetic averages for each rule-of-law-related variable.

The outcome of the research procedure outlined above is a classification of EU countries, which are categorized, as per Table 4, into four distinct areas (O1, O2, O3, O4). Each EU country is placed into only one of these areas based on its assigned classification. Given that there are eight variables related to energy policy, a single EU state may appear up to eight times across all the analyzed areas. Drawing conclusions about the impact of the rule of law on the energy sector necessitates the identification of groups of countries with similar characteristics.

The authors of this article suggest that the grouping of countries with similar relationships between the rule of law and energy policy should be carried out using the criterion of how often a given EU state appears in a particular area (O1, O2, O3, O4). Such an analysis will illustrate the frequency with which a particular EU country appears in a given area, such as O1. Frequent appearances of an EU country in area O1, indicating an above-average performance (e.g., Denmark or Finland, as shown in the Data Repository in Table 3a,b), can provide valuable insights (Data Repository [75])—this means that the country simultaneously respects the rule of law and observes and applies in practice elements of energy policy including green economy solutions. In contrast, if an EU country frequently appears in the O4 area—above average (see Bulgaria or Cyprus in the Data Repository in Table 3a,b) (Data Repository [75])—this means that the country has a low level of respect for the rule of law while lacking commitment to energy policies incorporating green economy solutions.

Tables 3a, 5a, 7a, 9a, 11a, 13a, 15a, 17a, 19a, and 21a in the Data Repository "Correlation of the Rule of Law with Energy Policy" (Data Repository [75]) show prepared summaries of the incidence counts of each EU country in a given area, either O1, O2, O3, or O4. The tables in the Data Repository were prepared as follows:

- In Phase I, EU countries were ranked, in absolute terms, according to the number of occurrences within the O1 area (col. 2 in Tables 3a, 5a, 7a, 9a, 11a, 13a, 15a, 17a, 19a, 21a in the Data Repository [75]),
- In Stage II, EU countries were ranked according to the number of occurrences within the O2 area, but taking into account the results of the ranking from Stage I (col. 3 in Tables 3a, 5a, 7a, 9a, 11a, 13a, 15a, 17a, 19a, and 21a in the Data Repository [75]),
- In Stage III, EU countries were ranked according to the number of occurrences within the O3 area, but taking into account the results of the ranking from Stages I and II (col. 4 in Tables 3a, 5a, 7a, 9a, 11a, 13a, 15a, 17a, 19a, and 21a in the Data Repository [75]),
- In Stage IV, EU countries were ranked according to the number of occurrences within the O4 area, but taking into account the results of the ranking from Stages I, I, and III (col. 5 in Tables 3a, 5a, 7a, 9a, 11a, 13a, 15a, 17a, 19a, and 21a in the Data Repository [75]).

The results in Tables 3a, 5a, 7a, 9a, 11a, 13a, 15a, 17a, 19a, and 21a in the Data Repository "Correlation of the Rule of Law with Energy Policy—Position of EU countries" (Data Repository [75]) are shown graphically in Figures 1–6.

Tables 3b, 5b, 7b, 9b, 11b, 13b, 15b, 17b, 19b, and 21b in the Data Repository "Correlation of the rule of law with Energy policy—Position of EU countries" (Data Repository [75]) show prepared summaries of the incidence counts of each EU country in a given area, O1, O2, O3, and O4. The tables in the Data Repository were prepared as follows:

- In Phase I, EU countries were ranked by incidence within the O1 area for incidences greater than or equal to 4 (col. 2 in Tables 3b, 5b, 7b, 9b, 11b, 13b, 15b, 17b, 19b, 21b in the Data Repository [75]),
- In Stage II, the remaining EU countries were ranked by incidence within the O2 area for counts greater than or equal to 4 (col. 3 in Tables 3b, 5b, 7b, 9b, 11b, 13b, 15b, 17b, 19b, 21b in the Data Repository [75]),
- In Stage III, the remaining EU countries were ranked by incidence within the O3 area for incidences greater than or equal to 4 (col. 4 in Tables 3b, 5b, 7b, 9b, 11b, 13b, 15b, 17b, 19b, 21b in the Data Repository [75])

- In Stage IV, the remaining EU countries were ranked by incidence within the O4 area for incidences greater than or equal to 4 (col. 5 in Tables 3b, 5b, 7b, 9b, 11b, 13b, 15b, 17b, 19b, 21b in the Data Repository [75]).

The factors were compiled based on the strategic management method—the strategic group map. In constructing these maps, key factors are used [31,83]. On the *X*-axis, energy policy factors are depicted, while on the *Y*-axis, rule of law factors are depicted. This is an application not yet used, until now, in this type of analysis. Indeed, analysis of a strategic group map is commonly used in the analysis of the competitiveness of businesses [84,85], and public organizations [86].

3. Research Results

3.1. Introduction

The authors of the article assume that the implementation of EU's energy policy, based on the principles of solidarity and cooperation among member states, leads to improved results in terms of energy security, environmental protection, and the prevention of dominance by any single country or entity in the energy market. Consequently, the effective implementation of EU energy policy relies on a strong commitment to the rule of law and the enhancement of democracy within member states. The rule of law plays a pivotal role in EU's energy policy, influencing how member states make decisions and achieve their energy-related objectives.

In countries with a robust rule of law, decisions regarding energy infrastructure investments, environmental protection, and electricity distribution are made transparently, following legal procedures and considering the interests of society. In contrast, in countries where the rule of law is weak, energy policy decisions can be susceptible to political influence or private interests, potentially leading to inefficient and inequitable allocation of resources and unsustainable development within the energy sector. This interpretation of the rule of law connects the business world, including market regulations, with values (axiology). Consequently, effectiveness, including participation in the EU budget, depends not only on mere adherence to legal norms but also on the (conditional) respect for human rights and ecological standards.

3.2. Analysis Results

The implementation of the methodological assumptions described in Section 2.5 facilitated the classification of the analyzed EU countries into the defined four areas, O1, O2, O3, and O4, utilizing the criterion of the number of EU countries in each area. This section will examine the relationships among selected rule of law indicators and all energy policy indicators.

As per the predefined assumptions, the following variables were analyzed in the context of the rule of law: (I) Rule of Law Index—overall score, (II) Constraints on Government Powers, (III) Open Government, (IV) Fundamental Rights, (V) Regulatory Enforcement, and (VI) Regulatory Quality Index. Tables and figures containing data on the Absence of Corruption, Order and Security, Civil Justice, and Criminal Justice factors have been included in the Data Repository titled "Correlation of the Rule of Law with Energy Policy." (Tables 14–21b and Figures 1–4 in the Data Repository [75]).

In the context of energy policy, the variables analyzed encompass contribution to renewable energy, total gross available energy, the Eco-Innovation Scoreboard, primary energy consumption, final energy consumption, the Effort Sharing Regulation, the level of electricity interconnectivity, and the energy market indicator.

3.2.1. Rule of Law Index—Overall Score (Data from Table 3a,b in the Data Repository [75])

As an overall summary of EU countries, encompassing all energy policy indicators and the overall scores in the Rule of Law Index, the data analysis presented in Figure 1 reveals that EU countries can be categorized as follows:

- Excelling in both the rule of law and the responsible implementation of energy policies including green economy elements are Denmark, Finland, Luxembourg, Spain, Austria, Estonia, Germany, Lithuania, and the Netherlands.
- Performing well in the rule of law and demonstrating a responsible approach to energy policies, including green economy elements, are Sweden, France, Czechia, Belgium, and Ireland.
- Struggling in terms of the rule of law and showing limited progress in energy policy, including green economy elements are Portugal, Romania, Slovenia, Malta, and Italy.
- Experiencing significant challenges in the rule of law and displaying limited advancement in energy policy including green economy elements are Latvia, Greece, Poland, Croatia, Hungary, Slovakia, Bulgaria, and Cyprus.

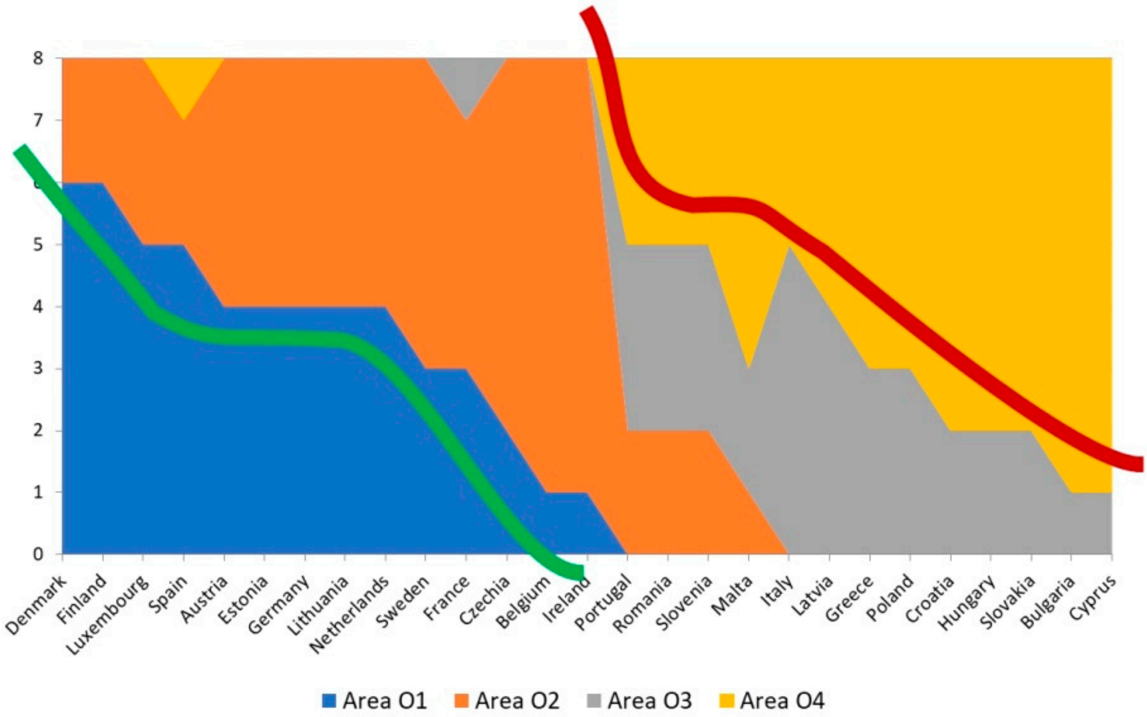

Figure 1. Areas: O1, O2, O3, O4—visualization for the indicator Rule of Law Index—overall score. Source: Data Repository [75]-data from Table 3a.

In Figure 1, the curves schematically delineate the separated areas, with O1 represented by the green line and O4 by the brown line for the rule-of-law-related variable Rule of Law Index—overall score.

A more detailed summary (Data Repository [75]-data from Table 3b) ranks countries based on the number of occurrences (count) within the O1 area as the primary criterion, followed by O2, O3, and O4. This ranking reveals the following:

- The countries excelling in both the rule of law and green economy policies are Denmark, Finland, Luxembourg, and Spain.
- The countries demonstrating a strong commitment to the rule of law but with some ambiguity in their approach to green economy policies include Austria, Estonia, Germany, Lithuania, and the Netherlands. France is ambiguously implementing brown economy policies.
- The countries with a strong adherence to the rule of law but pursuing brown economy policies are Ireland, Belgium, Czechia, and Sweden.
- Italy exhibits an issue with the rule of law (below average) while actively implementing green economy policies.
- Latvia faces challenges with the rule of law and lacks a clearly defined energy policy.

- Bulgaria, Cyprus, Croatia, Hungary, Slovakia, Malta, Greece, Poland, Romania, and Slovenia experience significant difficulties with the rule of law and are actively pursuing brown economy policies.

3.2.2. Factor: Constraints on Government Powers (Data from Table 5a,b in the Data Repository [75])

As an overall summary of EU countries, encompassing all energy policy indicators and Factor 1: Constraints on Government Powers, the analysis of the data depicted in Figure 2 reveals:

- Excelling in the rule of law and responsible implementation of energy policies, including elements of the green economy, are Denmark, Estonia, Finland, Luxembourg, Portugal, Spain, France, Austria, and the Netherlands.
- Demonstrating average adherence to the rule of law and average implementation of energy policies, including elements of the green economy, are Czechia, Germany, Sweden, Slovenia, Latvia, Croatia, Hungary, Slovakia, and Belgium.
- Struggling significantly with the rule of law and displaying limited implementation of energy policy, including green economy elements, are Bulgaria, Cyprus, Italy, Romania, Lithuania, Greece, Malta, Poland, and Ireland.

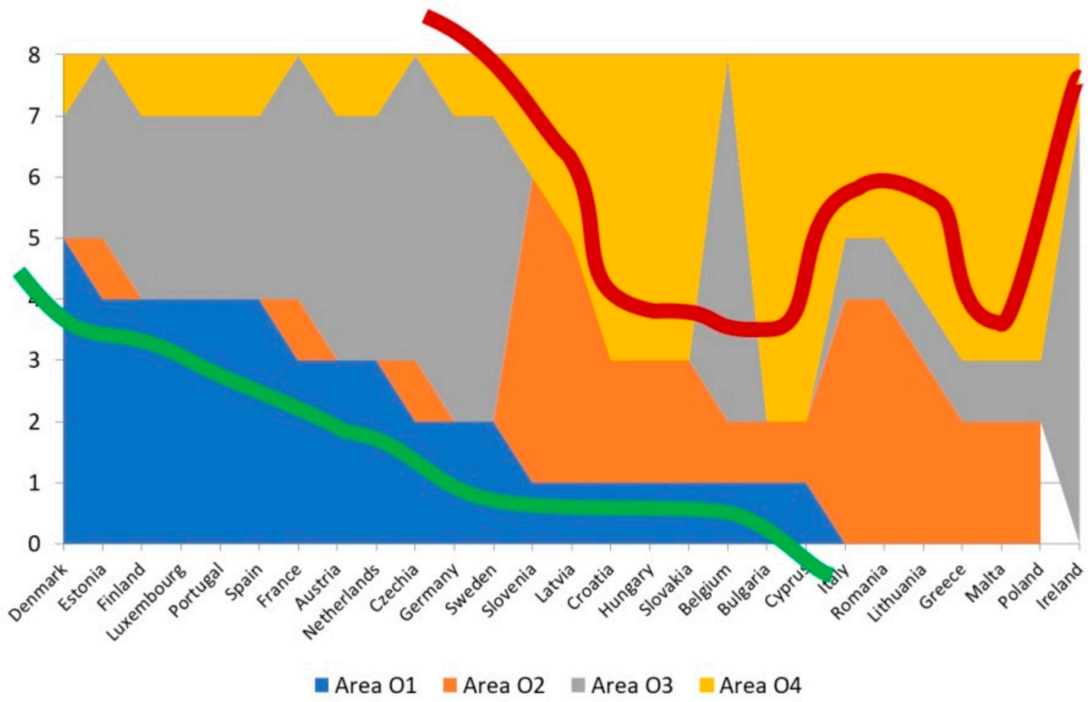

Figure 2. Areas: O1, O2, O3, O4—visualization for the indicator Factor 1: Constraints on Government Powers. Source: Data Repository [75]-data from Table 5a.

In Figure 2, the curves schematically delineate the distinct areas O1 (green line) and O4 (brown line) for the rule of law variable Factor 1: Constraints on Government Powers.

Analysis of the detailed data, considering Factor 1: Constraints on Government Powers (Data Repository [75]-data from Table 5b), reveals the following trends:

- The most law-abiding countries that also implement green economy policies are Denmark, followed by Estonia, Finland, Luxembourg, Portugal, and Spain.
- The countries that exhibit law-abiding tendencies but lean toward brown economy policies are Slovenia, Latvia, Italy, and Romania.
- The countries with a below-average score in the rule of law dimension of Constraints on Government Powers but still implementing green economy policies include Ireland, Belgium, Czechia, Germany, Sweden, France, Austria, and the Netherlands.

- The countries facing the most significant rule of law challenges and also implementing brown economy policies are Bulgaria, Cyprus, Greece, Malta, Croatia, Hungary, Slovakia, Poland, and Lithuania.

3.2.3. Factor: Open Government (Data from Table 7a,b in the Data Repository [75])

Analysis of the detailed data, taking into consideration Factor 3: Open Government (Data Repository [75]-data from Table 6b), reveals the following trends:

- The countries that perform exceptionally well in terms of the rule of law and the responsible implementation of energy policies, including elements of the green economy, are Denmark, Estonia, Latvia, Finland, Luxembourg, France, Lithuania, and the Netherlands.
- The countries that exhibit an average performance in terms of the rule of law and the implementation of energy policies, including green economy elements, are Slovakia, Germany, Malta, Sweden, Slovenia, Croatia, Czechia, Hungary, Belgium, and Cyprus.
- The countries with significant rule of law challenges and limited implementation of energy policy, including green economy elements, include Bulgaria, Italy, Portugal, Romania, Spain, Austria, Greece, Poland, and Ireland.

In Figure 3, the curves schematically indicate the separate areas, O1 (green line), and O4 (brown line), for the rule-of-law-related variable Factor 3: Open Government.

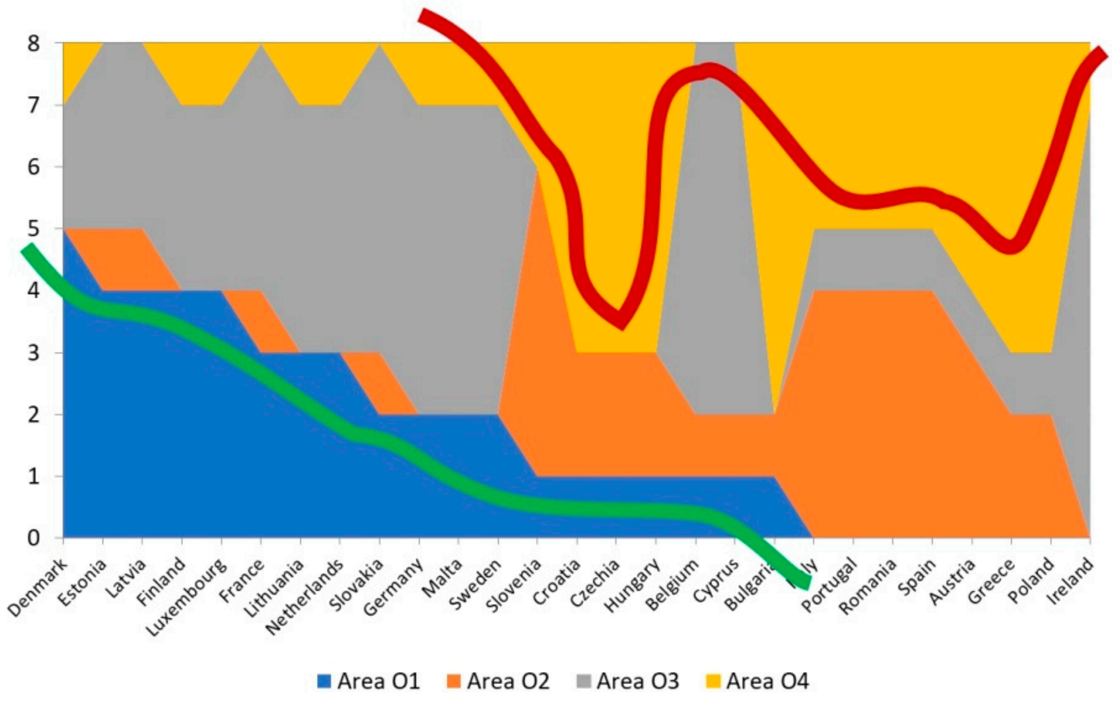

Figure 3. Areas: O1, O2, O3, O4—visualization for the indicator Factor 3: Open Government. Source: Data Repository [75]-data from Table 7a.

Analysis of the detailed data considering the factor "Open Government" (Data Repository [75]-data from Table 7b) reveals the following observations:

- Denmark, Estonia, Latvia, and Finland exhibit the highest level of adherence to the rule of law and actively pursue green economy policies.
- Luxembourg and France are actively involved in green economy policies but have undefined rule of law standings.
- Countries like Ireland, Belgium, Cyprus, Slovakia, Germany, Malta, Sweden, Lithuania, and the Netherlands face rule of law challenges in the context of "Open Government," yet they are actively implementing green economy policies.

- Slovenia demonstrates compliance with the rule of law while pursuing brown economy policies.
- Italy, Portugal, Romania, and Spain are focused on brown economy policies and have undefined rule of law standings.
- Bulgaria, Poland, and Greece, as well as Croatia, Czechia, Hungary, and Austria, confront significant rule of law issues and are simultaneously pursuing brown economy policies.

3.2.4. Factor: Fundamental Rights (Data from Table 9a,b in the Data Repository [75])

Using the overall summary of EU countries, which includes all energy policy indicators and Factor 4: Fundamental Rights, analysis of the data illustrated in Figure 4 shows that EU countries that:

- Achieve a high level of compliance with the rule of law and responsibly implement energy policies, including elements of the green economy—Denmark, Estonia, Latvia, Finland, Luxembourg, Austria, Lithuania, and the Netherlands.
- Demonstrate average adherence to the rule of law and moderately implement energy policies, including elements of the green economy—Slovakia, Germany, Malta, Sweden, Slovenia, France, Croatia, Czechia, Hungary, Belgium, and Cyprus.
- Experience significant rule of law challenges and exhibit limited implementation of energy policies, including green economy elements—Bulgaria, Italy, Portugal, Romania, Spain, Greece, Poland, and Ireland.

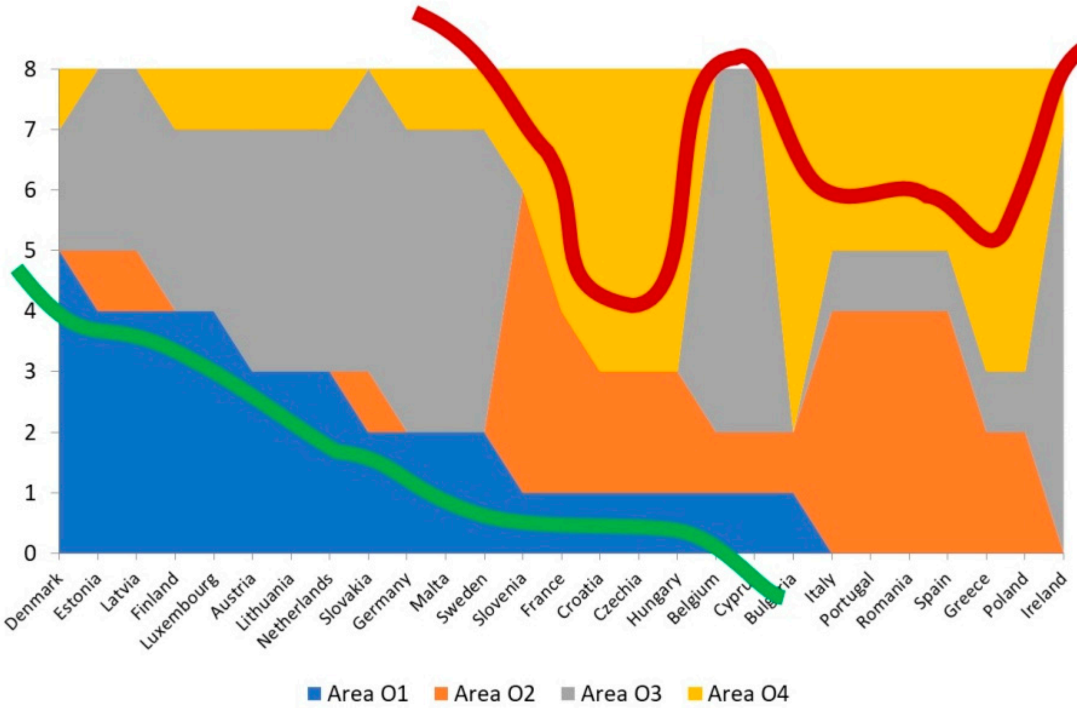

Figure 4. Areas: O1, O2, O3, O4—visualization for the indicator Factor 4: Fundamental Rights. Source: Data Repository [75]-data from Table 9a.

In Figure 4, the curves schematically indicate the separate areas, O1 (green line), and O4 (brown line), for the rule-of-law-related variable Factor 4: Fundamental Rights.

Analysis of the detailed data concerning Factor 4: Fundamental Rights (Data Repository [75]-data from Table 9b) reveals the following:

- The countries that demonstrate the highest adherence to the rule of law and actively implement green economy policies are Denmark, Estonia, Latvia, and Finland.
- Luxembourg and France are pursuing green economy policies but have an undefined status in terms of the rule of law.

- The countries with rule of law challenges in the Fundamental Rights dimension (below average) but actively implementing green economy policies include Ireland, Belgium, Cyprus, Slovakia, Germany, Malta, Sweden, Austria, Lithuania, and the Netherlands.
- Slovenia adheres to the rule of law and implements brown economy policies.
- Italy, Portugal, Romania, and Spain are pursuing brown economy policies but have an undefined status in terms of the rule of law.
- The countries facing the most significant rule of law challenges and actively implementing brown economy policies are Bulgaria, Poland, and Greece, followed by Croatia, Czechia, and Hungary.

3.2.5. Factor: Regulatory Enforcement (Data from Table 11a,b in the Data Repository [75])

In an overall summary of EU countries, which includes all energy policy indicators and Factor 6: Regulatory Enforcement, analysis of the data presented in Figure 5 reveals that EU countries can be categorized as follows:

- The countries that excel in both the rule of law and the responsible implementation of energy policies, including elements of the green economy, are Denmark, Estonia, Finland, Luxembourg, Spain, France, Austria, Lithuania, and the Netherlands.
- The countries that maintain an average level of rule of law and implement energy policies including elements of a green economy to an average extent include Czechia, Germany, Sweden, Slovenia, Latvia, Croatia, Hungary, Slovakia, and Belgium.
- The countries that face significant rule of law challenges and have limited implementation of energy policies including green economy elements are Bulgaria, Cyprus, Italy, Portugal, Romania, Greece, Malta, Poland, and Ireland.

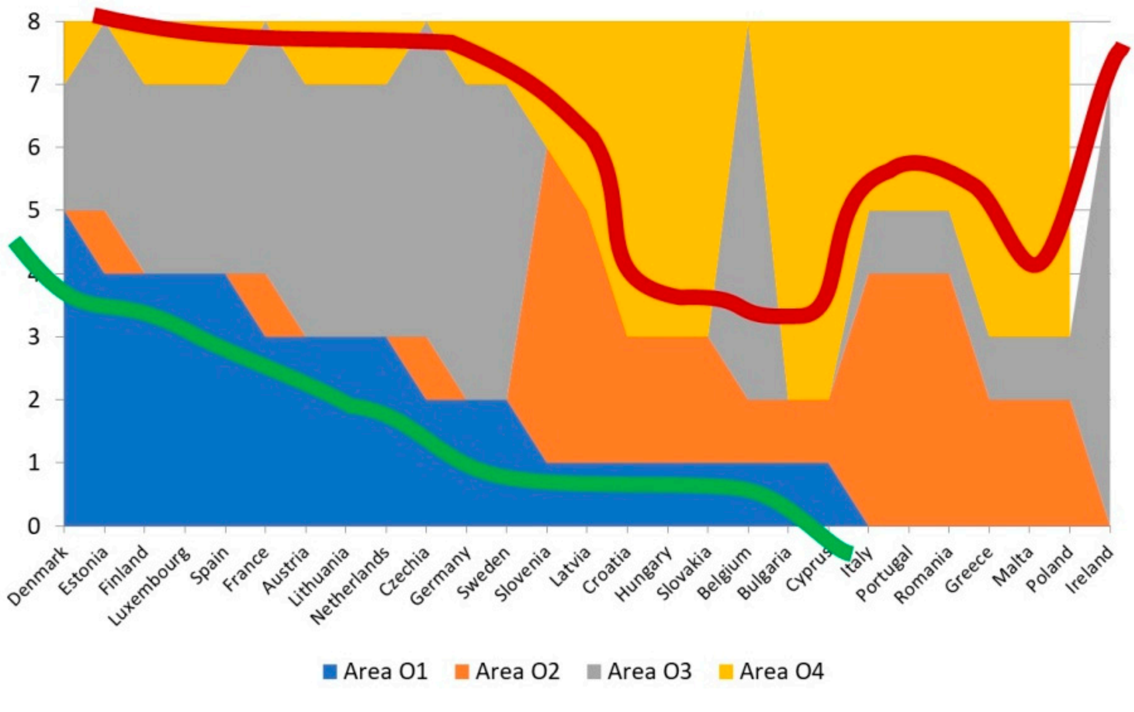

Figure 5. Areas: O1, O2, O3, O4—visualization for the indicator Factor 6: Regulatory Enforcement. Source: Data Repository [75]-data from Table 11a.

Figure 5 provides a visual representation of these categories, with the curves schematically indicating the separated areas of O1 (green line) and O4 (brown line) for the rule-of-law-related variable Factor 6: Regulatory Enforcement.

From analysis of the detailed data considering Factor 6: Regulatory Enforcement (Data Repository [75]-data from Table 11b), the following insights can be drawn:

- The countries that are most law-abiding and actively implement green economy policies are Denmark and Estonia.
- Finland, Luxembourg, and Spain are pursuing green economy policies, but their status regarding the rule of law is undefined.
- There is a rule of law problem in the Regulatory Enforcement dimension (below average) but the implementation of green economy policies is visible in countries like Ireland, Belgium, Czechia, Germany, Sweden, France, Austria, Lithuania, and the Netherlands.
- Slovenia and Latvia maintain a law-abiding status but implement brown economy policies.
- Italy, Portugal, and Romania are actively pursuing brown economy policies but also face rule of law challenges.
- The countries with the most significant rule of law issues and simultaneous implementation of brown economy policies are Bulgaria, Cyprus, Croatia, Hungary, Slovakia, Poland, Greece, and Malta.

3.2.6. Regulatory Quality Index (Data from Table 13a,b in the Data Repository [75])

Using an overall summary of EU countries, including all energy policy indicators and the Regulatory Quality Index, the analysis presented in Figure 6 reveals that EU countries can be categorized as follows:

- Those who excel in both the rule of law and the responsible implementation of energy policies, encompassing green economy elements, are Denmark, Estonia, Latvia, Finland, Luxembourg, France, Austria, and the Netherlands.
- The countries that maintain an average level of rule of law and implement energy policies including green economy aspects are Czechia, Germany, Malta, Slovenia, Bulgaria, Croatia, Hungary, Slovakia, Belgium, and Cyprus.
- The countries with significant rule of law challenges and limited progress in energy policy, particularly in green economy areas, include Italy, Portugal, Romania, Spain, Lithuania, Sweden, Greece, Poland, and Ireland.

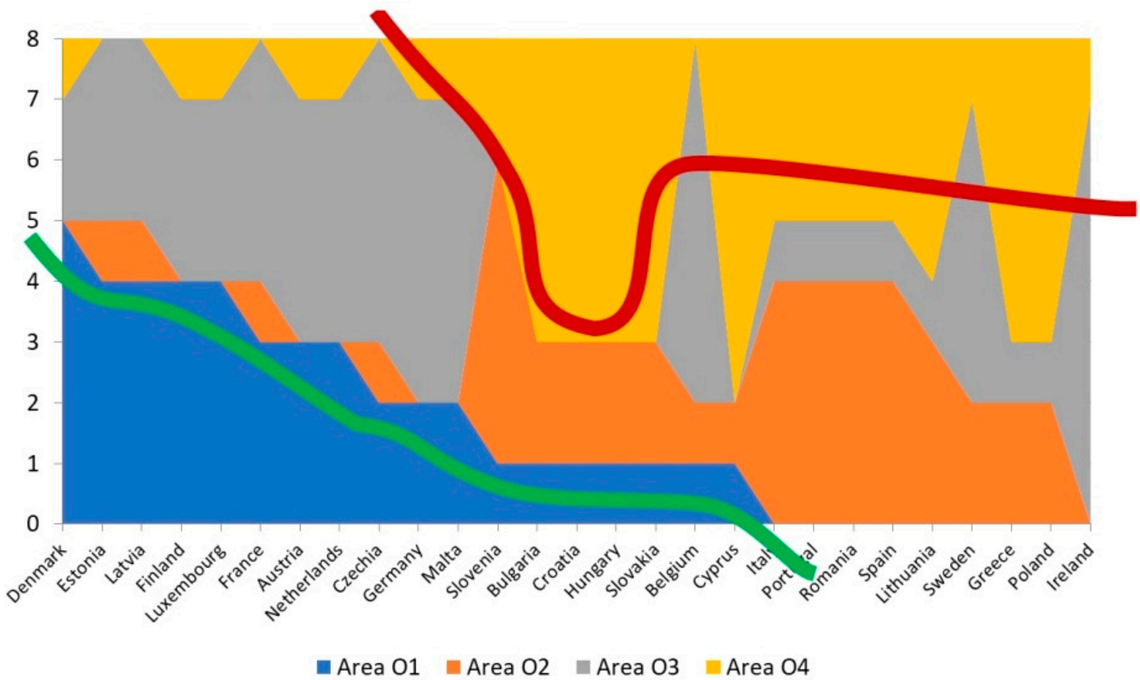

Figure 6. Areas: O1, O2, O3, O4—visualization for the indicator Regulatory Quality Index. Source: Data Repository [75]-data from Table 13a.

In Figure 6, the curves schematically delineate the distinct areas O1 (green line) and O4 (brown line) for the variable related to the rule of law the Regulatory Quality Index.

From analysis of the detailed data considering the factor Regulatory Quality Index (Data Repository [75]-data from Table 13b), the following observations can be made:

- The countries most committed to the rule of law and the implementation of green economy policies are Denmark, Estonia, and Latvia.
- Finland, Luxembourg, and France are pursuing green economy policies but have undefined rule of law standings.
- There is a rule of law deficiency in the dimension of the Regulatory Quality Index (below average) but the implementation of green economy policies is evident in Ireland, Belgium, Czechia, Germany, Malta, Sweden, Austria, and the Netherlands.
- The countries that adhere to the rule of law but implement brown economy policies include Slovenia.
- Italy, Portugal, Romania, and Spain have undefined rule of law standings and are pursuing brown economy policies.
- The most substantial rule of law challenges combined with the implementation of brown economy policies are experienced by Bulgaria, Cyprus, Poland, Greece, as well as Croatia, Hungary, Slovakia, and Lithuania.

4. Discussion

The reasons why energy policies in line with EU guidelines are being overlooked and/or sluggishly implemented in Poland and other EU countries at the tail end of the energy modernization process should be sought at several levels and linked to policies on compliance with the rule of law.

The research results presented in Section 3 and the positioning of EU countries in the matrix in Table 4 provide the basis for the following discussion. The groups of countries obtained in this way allow us to notice that Denmark, Estonia, and Finland can be considered countries that clearly meet the high requirements of the rule of law and at the same time implement a fully green energy policy. This follows directly from the conclusions presented in Figures 1–6. At the general level of the analysis, it can be noted that these countries have in common not only their location in the north of Europe (Nordic countries) but also on the Baltic Sea. These countries therefore represent a specific cultural identity—Nordic culture. Another equally important argument explaining the high level of rule of law and energy policy is the fact that these are small state entities in terms of population—Finland, 5.5 million; Denmark—5.8 million; and the smallest being Estonia—1.3 million. Smaller state entities are probably more effective in terms of state management, which translates into the quality of their energy policy and rule of law. This arguably allows for greater control in smaller societies. Unfortunately, this argument is not very convincing if we take into account countries from a completely opposite group with the lowest level of rule of law and brown energy policy, such as Croatia and Greece. These are also small countries in terms of population.

The research team proposes taking as the main argument explaining the obtained research results the type of religion dominant in a given country, and more broadly, the attitude of the citizens of this country to religion as a fundamental relationship characterizing the leaders of the rule of law and green economy (Figure 7).

This is, in a way, the result of the culture professed and propagated—whether it is the culture of Nordic countries, of Central European post-socialist countries, or of Balkan countries. The analysis was based on two datasets. The first was analyzed by the Pew Research Center [87,88], which, although it is not the most recent (2011–2012), allows for a comparison of all the countries discussed here in the same period. Analysis of the latest data available for only some of these countries confirms the general structure and the trend shown in the Pew Research Center's research. The second group of data comes from the Association of Religion Data Archives [89]. The presented Pew Research Center and ARDA data will be separated by slashes.

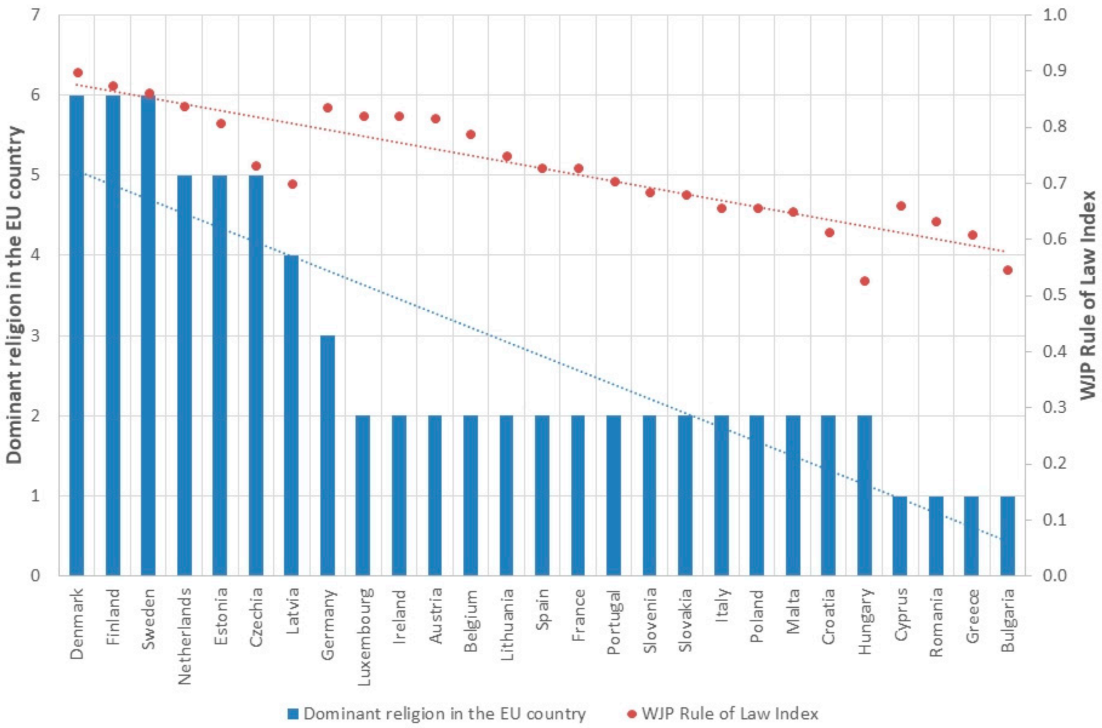

Figure 7. Relationship between dominant religion in an EU country [74] and its WJP Rule of Law Index—EU countries ranked by dominant religion. Source: own study. P—Protestant; NR—Non-Religious; C/NR—Catholic/Non-Religious; C/P—Catholic/Protestant; C—Catholic; EOC—Eastern Orthodox Christians.

The author's team proposes making the following comparison, which is the basis for the main discussion in the article. Denmark being the most visible leader in the rule of law and green economy is characterized by the fact that it is one of the most secularized nations in the world. Religious indifference, agnosticism, and, to a lesser extent, atheism are common. According to the Pew Research Center and ARDA, Protestantism constitutes 81.9%/77.7%, no religion 11.8%/12.81%, Islam 4.1%/5.26%, and Catholicism 0.7%/0.78%. The Lutheran Church dominates among Protestants. Belonging to the state Lutheran Church is a sign not so much of religiosity but of national identity [87–89].

A similar relationship can be noticed when analyzing the religious structure of Estonia. It is a highly secularized country, but the traditional religion is Lutheranism. The religious structure of the country in 2010 according to the Pew Research Center was Protestantism—21.2%/14.47% (mainly Estonians, as well as Finnish and Latvian national minorities), Orthodox Christianity—18.9%/12% (mostly Russian-speaking national minorities), Catholicism—0.7%/0.44% (mainly Poles and Lithuanians), other branches of Christianity—0.5%/1.01%, Islam—0.2%/0.28%, and Judaism—0.1%/0.11%. A total of 58.4% of citizens were undeclared religiously. Therefore, next to the Czech Republic (72%), it is the most secularized country in Europe [87–89].

The dominant religion in Finland is Protestantism. The Finnish Evangelical Lutheran Church and the Finnish Orthodox Church have the status of national churches. Thanks to this, they have special privileges, and the faithful pay taxes on their behalf. The percentage of people who believe in God and recognize the basic truths of the Christian religion is higher than in other Nordic countries. In the case of Finland, the Evangelical Lutheran Church of Finland has the largest share at 80.2%/72.57%, and the Orthodox Church has 1.1%/1.19%, while 17.6%/19% have no denomination. The decline in this share of the main church in Finland since 1950 is over 30% (in 1950, 95.7%, when only 2.7% of citizens had no religion) [87–89].

Based on the above conclusions, it can be concluded that in countries where Protestantism dominates and there is a significant proportion of non-believing citizens, there is a connection between a high level of rule of law and advanced modernization energy policy implemented in accordance with the adopted obligations. The countries with this type of dependency include: Denmark, Finland, Estonia, and Lithuania.

The research results presented in Section 3 allowed us to notice that the countries that are clearly not law-abiding and implementing a brown economy can be considered mainly Bulgaria, followed by Croatia and Greece. So, these are Balkan countries. They are immediately followed by Poland and Hungary, i.e., Central European countries. What connects these groups of Balkan countries and Central Europe? These are countries that differ from the group of law-abiding countries committed to implementing a green economy by their strong attachment to religion (a small number of non-believers) and where the Catholic religion dominates.

Bulgaria as a leader in its lack of rule of law and in its brown economy is characterized by the following religious structure: Orthodox Christianity 83%/80.88%, Islam 13.7%/13.62%, Protestantism 0.6%/2.01%, Catholicism 0.5%/1.05%, and non-believers 4.2%/4.19%. It is therefore the most Orthodox country analyzed here [87–89]. Next, close to each other—and far behind Bulgaria—are Croatia and Greece. In Croatia, Catholics are the largest group at 88.5%/83.58%. The next groups of believers are Orthodox at 4.4%/5.6%, Muslim at 1.4%/1.89%, and Protestants at 0.3%/0.84%. Non-believers constitute 5.1%/4.32% [87–89].

The religious structure of Greece is as follows: Orthodox Christianity 88.3%/87.98%, Islam 5.3%/5.83%, Catholicism 0.7%/1.32%, Protestantism 0.3%/0.23%, and non-believers 6%/6.1% [87–89].

The next two countries in this infamous ranking were Poland and Hungary. Let us look at the religious structure in these countries. Poland stands out in Europe due to the very high share of the Catholic religion there—92.2%/90.1%, compared to Orthodox Christianity at 1.3%/1.53% (mainly residents of the eastern and south-eastern parts of the country—Ukrainian and Belarusian minorities) and Protestantism at 0.4%/0.35%. The rate of non-believers was 5.6%/4.24 [87,88,90]. Hungary is distinguished from Poland by a much larger shares of non-believers in this structure—18.6%/11.85%—and of the Protestant religion—21.6%/26.09%. Also, like in Poland, the Catholic religion is dominant 60.6%/60.04%. There is a negligible share of the Orthodox religion—0.1%/1.54%—and Islam—0.3%/0.32% [87,88,90].

Based on the above conclusions, it can be concluded that in countries where the Catholic or Orthodox religion dominates, there is a relationship between a low level of rule of law and a very conservative energy policy implemented as a brown economy. The countries with this type of strong dependency include Bulgaria, Greece (with dominant Orthodox religion), Croatia, Hungary, and Poland (with dominant Catholic religion). The common religious roots of these two subgroups of countries have important determinants, which was also indicated in the analysis carried out by the Pew Research Center in 2017 [90]. Therefore, the approach to ecology in the form of the proposed and implemented energy policy has much deeper foundations than it initially seemed. The sense of need for and compliance with the rule of law, correlated with a responsible and sustainable approach to the environment, nature, and energy, has ontological foundations. It is an expression of an approach to life and the world and its practical implementation. Either this approach is very responsible toward the environment and people or it is less responsible.

In countries where Protestantism predominates, this correlation falls positively and is at a high level, which translates to a high level of rule of law and advanced modernizing energy policies implemented in accordance with the commitments made. The countries with this type of correlation include Denmark, Finland, Sweden, the Netherlands, and Estonia. The opposite is true for countries where Catholic or Orthodox religions predominate, e.g., Bulgaria, Greece, Romania, Cyprus, Hungary, Croatia, Malta, Poland, Italy. This dependence may be related, of course, to the level of wealth of these countries, but its causes can also be linked to their approach to the phenomenon of communitarianism, the way it is realized, and the related understanding of the importance of civil society and public participation in the creation and implementation of and accountability in politics. In the official documents of the European Union, churches are treated as institutions of civil society and are credited with the role of involving citizens, especially in local affairs. As explained by Wioletta Szymczak, people involved in these organizations of religious provenance can be seen, on the one hand, as implementers and carriers of the norm of commitment to the common good and social solidarity and religious or church organizations as schools of civic virtues or, on the opposite pole, as sources of alienation, ghettoization, and opposition to democratic values such as freedom, autonomy, and tolerance [91].

Given the close ties between the Catholic Church in Poland and the ruling conservative coalition, this relationship may translate into support for the policies of a government that is tarnished in terms of its rule of law and passive in terms of its energy policy commitments. In contrast to the above, with regard to Protestantism, by contrast, it is worth pointing to the results of R. Inglehart's research in the World Value Survey, on which is written that "When the propensity to cooperate was taken into account as measured by attitude toward the law (trust in the legal system, acquiescence in breaking the law, such as tax fraud, giving bribes, among others), the overall conclusion was that Protestants trusted other people and the legal system more, and were less likely to accept tax fraud and bribes than Catholics. Catholics, on the other hand, supported private property twice as strongly as Protestants and were characterized by the highest support for the principle of competition among representatives of all denominations. Protestantism had a strong influence on the formation of attitudes conducive to civil society because it gave trust and knowledge not only a metaphorical, but a measurable character. It formed a specific type of culture, which for its duration and intergenerational reproduction no longer needed religion for the permanence and strength of civil society [92]."

Taking into account the results of the survey conducted, there is a clear polarization between the countries of the poorer European south and those of the richer north. In the former, the factors related to economic costs entailing social costs seem to take precedence over issues related to the rule of law in these countries and the implementation of commitments made at the supranational level of the EU political system. This may be due to the too-short period of functioning in the European Union and the "breathlessness" of the societies of these countries associated with the constant need to "catch up" with richer countries in the sphere of economic development (Figure 8). This pursuit is carried out on the basis of multi-generational sacrifices, in which some social groups no longer want to be active or do not keep up with the pace of change. Their attitudes and views on too much change and misunderstood progress provide fodder for a growing number of populist or national-conservative parties proposing simple prescriptions to stop it, including denying or disregarding the rule of law in countries where they have taken the helm of power. This trend is noticeable in a number of EU member states but is particularly accentuated in those countries of the south that joined the EU after 2004 (Figure 8).

Also to be considered is the observation of the influence of the dominant religion/religion on the correlation between the level of rule of law and the energy policies of member states (Figure 8). And at this level, there seem to be determinants of the correlations between the rule of law and the dynamics of change in the energy sector in EU countries.

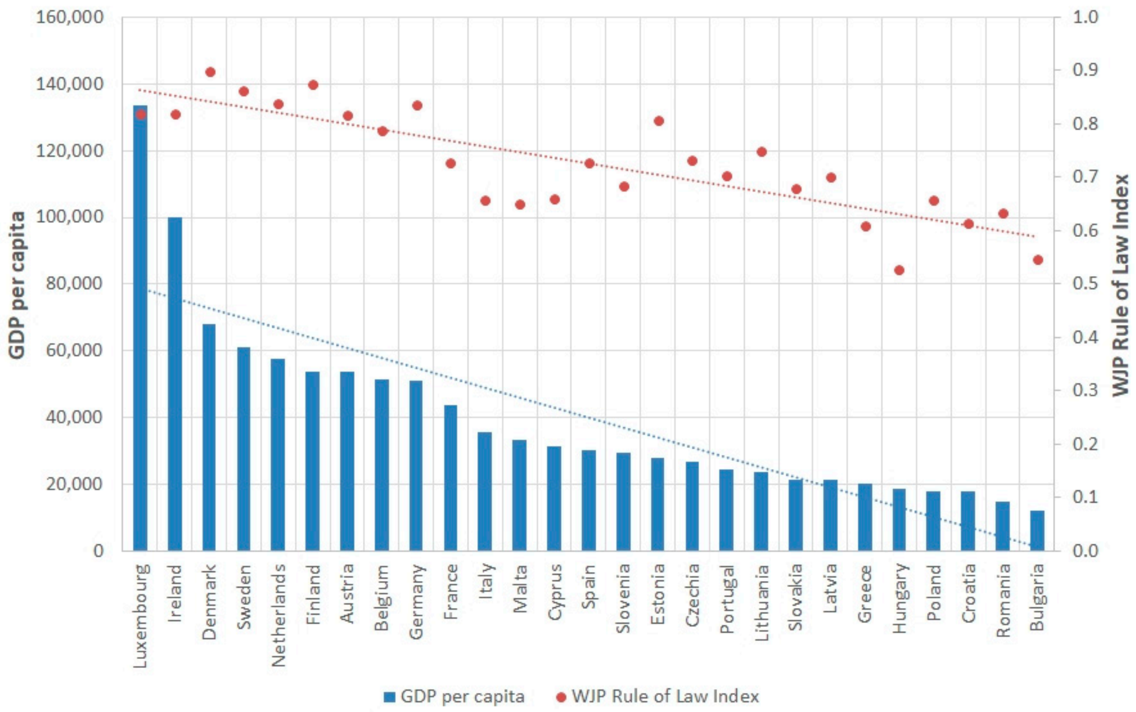

Figure 8. Relationship between GDP per capita and the WJP Rule of Law Index—EU countries ranked by GDP per capita [current dollars, 2021] [74]. Source: own study.

5. Conclusions

5.1. Recommendations on the Rule of Law and Energy Policy

Examining the correlation between the level of rule of law in EU member states and the implementation of the European Union's energy policy has not attracted attention from researchers so far. The originality of such research lies in rejecting the separateness of the problem of adherence to the rule of law principles in EU member countries from the problem of implementing energy policy resulting from the normative acts adopted at this level. This article's authors believe that this less noticeable dependency deserves examination and the verification of previous convictions.

The content of this article allows for the identification of the correlations between the level of rule of law in European Union countries and the fulfillment of obligations arising from EU policies, in this case, energy policy. Analyses enable the identification of countries and governments that demonstrate loyalty to EU commitments, pursuing their national interest in line with European interests, as well as those prioritizing other interests over European ones.

The main conclusions of the study are as follows:

- The EU's energy policy is determined by a number of factors, one of which is the level of rule of law in various member countries.
- The rule of law (and its level) in a given country influences the implementation of energy policy resulting from the need to implement EU law and implement solutions that fulfill it.
- A low level of rule of law in an EU member state can contribute to delays in or the deformation of the energy policy objectives implemented by that state within the framework of the whole that is the EU.
- The most significant influence on the effectiveness of the implementation of EU laws and obligations to other member states—linked to the rule of law—in the area of energy policy is related to "Fundamental Rights" and "Order and Security" (see FR and OS in Table 2).

- In the EU, the best performers in terms of the rule of law and responsible implementation of energy policy are Denmark, Finland, Luxembourg, and Spain. In the EU, performing very badly with the rule of law and implementing energy policy in a limited way are Latvia, Greece, Poland, Croatia, Hungary, Slovakia, Bulgaria, and Cyprus.

The conclusions from the analysis presented in the article have utilitarian value, providing scientific foundations for EU institutions to introduce disciplinary solutions for member states that violate or fail to adhere to the rule of law, harming the dynamics of its implementation in the Union as a whole.

EU activities should be differentiated and depend on the classification used in Table 4. Group O1 can serve as a benchmark for other EU countries—Benchmark Strategy Group Countries (BSGCs). Group O2 requires an EU policy directed at strengthening its activities related to improving the rule of law—"Money" for the "Rule of Law" (MRoL). In contrast, the O3 group requires thorough economic support to develop a modern energy sector—"Money" for "Green Activities" (MfGA).

The most problematic and challenging for the EU is the O4 group, which has been widely described in academic discussion (see Section 4). The most restrictive policies should be pursued against the countries in this group (O4)—that is, among other things, the application, by analogy, of the rule of law or the introduction of the new "Money" "Green Energy" (MfGE) principle. This indicates the priority of EU action on energy policy and the rule of law.

This research and its conclusions also allow for the identification of specific characteristics of the rule of law with a significant or insignificant impact on the implementation of energy policies adopted by EU member states. The results of these analyses can serve as benchmarks for disciplinary actions by EU institutions toward member states to maintain coherence and the expected dynamics of the organization's development.

5.2. Limitations of Research

In the course of collecting the research material, preparing the methodological assumptions, conducting the research, and preparing the text, several limitations of research were identified. The most important ones are indicated below.

5.2.1. Theoretical Limitations

One limitation of the article, identified in this area, is the lack of scientific articles examining the relationship and correlation between the rule of law and energy policy, assuming that we use quantitative variables. Analyzing the correlations for these two different, and often so distant in content, areas of science can cause scientific cognitive dissonance. However, the research conducted shows that the problems identified are apparent.

The research attempt undertaken is one of the first in this area of science. As such, references to the literature are indirect, and the research method adopted is pioneering in nature. On the one hand, this may attest to the originality of the study, thereby filling a scientific gap in this area, while on the other hand, its uniqueness may attest to an unusual approach and raise cognitive objections.

5.2.2. Methodology Limitations

The variables adopted in the article were collected from various commercial and non-commercial sources. Energy policy data are scattered, and variables are often difficult to compare substantively and numerically.

Another limitation stems from the difficulty of obtaining data caused by the problem of the availability of energy policy data. These data are collected in heterogeneous databases by many different institutions. As a result, the data are of limited analytical quality. At the same time, there is a large variety of data, which forced the authors of the article to select only some variables describing energy policy.

Not all data on the rule of law were available for 2020. This gave rise to the need to supplement the data. For this purpose, data from 2021 were used, assuming that they better showed the research trends. This information is described in the Data Sources and Transformation section.

The limitation also extends to the geographic aspect—the survey covered only European Union member states.

The discussion carried out in this article focused on the most clear-cut countries for analysis, which represent the benchmark (O1 countries) and those that cause the most problems, representing a priority for EU action (O4 countries).

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Review

An Analysis of the Development of the Cogeneration Sector in Spain: A Comprehensive Review of the Period 1980–2020 from a Regulatory Perspective

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Abstract: Combined Heat and Power (CHP) has been identified by the EU as a powerful resource capable of making substantial contributions to energy savings and reducing GHG emissions. Spain's effort to promote CHP has been prolific since the 1980s. In this regard, there have been various Laws, Royal Decrees (RDs) and European Union (EU) Directives addressed to reach the national objectives set for the CHP sector. Despite these attempts, the evolution and growth of installed CHP capacity has been irregular, compared to other technologies. Likewise, the academic treatment of the Spanish CHP evolution has not deserved the same attention as other technologies such as wind, photovoltaic and thermal solar systems. As a result, this article is aimed at providing a comprehensive overview of the regulatory frameworks applied to the Spanish CHP sector and analysing the reasons behind the variable evolution of the installed CHP capacity. The study covers the legislative context from 1980 to 2020, describing the evolution during both the pre-liberalization and liberalization periods, highlighting the modifications in economic policies that affected self-producers and the so-called Special Regime (SR) for CHP, and examining the challenges faced during the cost containment measures that followed. The manuscript finds and explains the connection between the regulatory framework and the evolution of installed CHP capacity in Spain. Likewise, the connection between the industrial situation and the promotion of CHP, as well as the influence of the Spanish Electricity Sector (SES)'s liberalization on the CHP sector are also pointed out. The paper intends to provide valuable insights for CHP experts and policymakers by showcasing the importance of aligning regulatory measures with the objectives of energy efficiency. It also serves as a reference for countries in various stages of promoting CHP, and provides evidence for the importance of stable energy-policy control mechanisms.

Keywords: cogeneration; CHP; self-production; regulatory framework; energy policy; special regime; promotion; Spanish electricity sector; Spain

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1. Introduction

Energy efficiency is identified as one of the five "mutually reinforcing" and "closely-interrelated" dimensions of the Energy Union strategy, together with energy security, the integrated European energy market, decarbonization of the economy and research, innovation and competitiveness [1], as well as a fundamental element of the European 2020 Strategy for smart, sustainable and inclusive development [2]. It is considered the "first fuel" [3], and consequently, it assumes a crucial role in the achievement of net-zero emissions in 2050 and the decarbonization process of the industrial sector of the European Union (EU) [4]. Many efforts have been carried out in recent years to increase the energy efficiency of the EU, requiring Member States to adopt measures that would allow them to increase energy efficiency by 20% by 2020 [5], with this value then updated to 32.5% when compared with projections of the expected energy use in 2030 using the Energy Efficiency Directive 2018/2002 [6].

Combined Heat and Power (CHP), or cogeneration, is an untapped resource that the EU recognizes as a significant contributor to saving primary energy, reducing greenhouse gas emissions (GHGEs), and avoiding network losses. The efficient use of energy by cogeneration positively impacts the energy supply's security and enhances the EU's and its Member States' competitiveness [7]. The Energy Efficiency Directive enables EU countries to conduct a comprehensive cost–benefit analysis of the potential for efficient heating and cooling, including cogeneration assessment [6].

Cogeneration has captured the interest of the academic community. Research on cogeneration has mostly focused on its technical and economic aspects such as the modelling of CHP plants and optimization problems [8–13], energy analysis, and cost–benefit analysis [14–19]. Studies have also explored the use of cogeneration in district heating and cooling [20–27]. However, the impact of regulatory frameworks on the promotion of CHP has received less attention in comparison to renewable energy systems (RES). Although, some relevant exemptions can be found in this field. Moya [28] analyses the influence of the various support measures and barriers on the evolution of cogeneration in Europe, while Colmenar-Santos et al. [29] present possible measures to eliminate the institutional and financial barriers that affect the expansion of cogeneration combined with district heating in the EU-28 landscape. Kavvadias [30] also highlights the main obstacles to the diffusion of combined energy generation and presents some proposals to minimize the exposure to the risk of investments in energy efficiency. Malinauskaite et al. [31] evaluate the measures taken in Spain and Slovenia in terms of energy efficiency in the industrial sector, including those related to the promotion of CHP. Westner et al. [32] present an overview of different support mechanisms for CHP applied in various European countries for a mean-variance portfolio analysis. Another interesting study was made by Uran et al. [33], which presents a method for the correction of the applied Feed-in Tariff (FIT) in Croatia in comparison with EU countries. The study conducted by Rivera-Alvarez et al. [34] is based on the comparison between the different incentives provided for cogeneration with natural gas (NG) in the various countries of South America. Ciarreta et al. [35] analyse the effects of liberalization on the Spanish electricity market and the problems that concern it. Bianco et al. [36] focus on the effects of the massive penetration of renewables, including CHP, on the Spanish electricity generation sector. Similarly, Simoglou et al. [37] carry out a study on the effects of RES integration, including CHP in this group, on the Greek electricity market. Finally, Gelabert et al. [38], on the other hand, conducted a study on the influence of RESs and cogeneration on electricity prices in Spain.

In this regard, Spain has been one of the most prolific EU countries when promoting RESs and CHP. However, to the best of the authors' knowledge, there is no comprehensive analysis of the several economic and regulatory frameworks affecting Spain's CHP sector from the beginning of its promotion to the present moment. Additionally, the evolution of the CHP-installed power in Spain has shown almost negligible variations since the 2000s, despite the various European directives and Royal Decrees (RDs) designed to promote this technology. This trend is decidedly different from that shown by RES technologies, such as Concentrated Solar and Photovoltaic systems, which underwent an evolution consistent with the several regulatory frameworks adopted through the years, as observed by Martín et al. [39], de la Hoz et al. [40] and Coronas et al. [41]. Hereof, this academic work aims to address the two gaps mentioned above. On the one hand, it will provide a comprehensive overview of the several regulatory frameworks to which the CHP sector was subject from 1980 to 2020. And, on the other hand, it will analyse the underlying causes of the apparent decoupling of the CHP deployment in Spain and its regulatory frameworks. In this way, it is intended to provide valuable lessons for experts and policymakers in the CHP sector.

This work is divided into five sections, which follow the introductory section. Section 2 outlines the methodology followed in our study. Section 3 provides the legislative context concerning cogeneration in Spain from 1980 to 2020, including European directives, RDs issued during this time, national energy-saving and efficiency plans, and the results achieved. Section 4 offers a detailed description of the regulatory frameworks identified in Section 3 for the years 1980–2020. In Section 5, there is a critical and detailed analysis of the evolution of the CHP sector in Spain, aimed at understanding the reasons behind the lack of responsiveness to the applied promotion mechanisms. Finally, in Section 5, the conclusions are presented.

2. Methodology

This section briefly outlines the systematic approach employed to investigate and analyse the key aspects of our research topic, aiming to provide a comprehensive understanding of the research process. An outline of all the steps followed in the research method used to write the manuscript is provided in Figure 1.

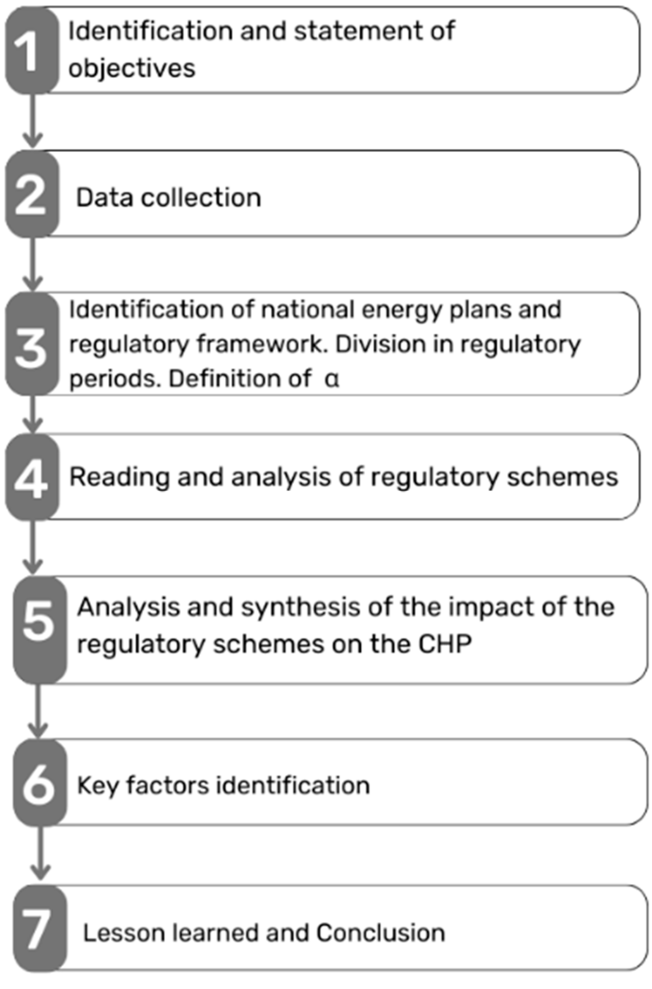

Figure 1. Outline of the methodology used to write the paper. Source: self-elaboration.

The first phase of our study, indicated in Figure 1 with point 1, aimed at the identification and formulation of the topic and the objectives of our research. Following this, as highlighted in point 2 of Figure 1, an exhaustive data collection process was undertaken to determine the values of installed CHP capacity and regulatory policy goals. The following part of our research involved the identification of national energy plans and the examination of the evolution of the Spanish regulatory framework. This framework was then subdivided into distinct regulatory periods to establish the correlation between the regulatory context and the implementation of CHP in the country (point 3, Figure 1). In the same phase, the installation rate, denoted as α, was defined as a tool to quantify and express the link between the Spanish energy policy and the installed CHP capacity. An in-depth analysis of regulatory schemes was conducted to understand their nuances and implications, as reported in point 4 of Figure 1. The impact of these diverse regulatory frameworks on the evolution of installed CHP capacity was then examined and synthesised (point 5 in the scheme in Figure 1). Afterwards, the study proceeded to pinpoint key factors influencing the evolution of installed CHP capacity specifically within the Spanish context, as indicated in point 6, Figure 1. Drawing upon the insights gained, the lessons learned were articulated, culminating in a conclusive summary (point 7, Figure 1).

3. The Spanish Cogeneration Policy—Contextualization, Main Goals and Results

The Energy Conservation Law 82/1980 [42] initiated the impetus for cogeneration in Spain. This law introduced a remuneration system for facilities that utilized renewable energy sources and cogeneration. Its primary objective regarding cogeneration was to harness the residual energy generated by industrial processes and convert it into electricity. The "self-producer" was a regulatory concept employed to achieve this goal. To encourage self-production and develop Law 82/1980, RD 907/1982 [43] was put into effect. This was followed by the National Energy Plan 1991–2000 (NEP 1991–2000) [44] publication, which included measures, actions, and objectives outlined in the Energy Efficiency and Savings Plan Annex (PAEE 1991–2000) [44]. The PAEE 1991–2000 policy goal was to increase the installed capacity of CHP by 1263 MW by the end of 2000, reaching a total of 2222 MW [44].

In 1994, Law 40/1994 was enacted to regulate the Spanish Electricity Sector (SES) [45], partially repealing Law 82/1980. This law distinguished between conventional power plants and new renewable and cogeneration systems, creating a Special Regime (SR) for the latter. This was a positive step towards promoting high-efficiency cogeneration, as the SR benefited from a differentiated economic framework. Later, in 1994, RD 2366/1994 [46] was enacted to produce electricity through pumping, cogeneration, and other systems supplied by renewable energy sources. This developed the economic framework for the SR, which included CHP plants rated up to 100 MW and satisfying specific energy efficiency requirements [46].

Starting from 1997, the SES initiated a process of liberalization that is still ongoing and is regulated by Law 24/2013. Throughout this liberalization period, multiple regulatory frameworks were established to encourage the promotion of RES, such as RD 2818/1998 [47], RD 436/2004 [48], RD 661/2007 [49], and RD 413/2014 [50]. The purpose of these frameworks was to accomplish the energy plans that were in place during those years. In this regard, and following the NEP 1991–2000 [44], Spain approved the Energy Saving and Efficiency Strategy (E4) in November 2003 [51]. The goal was to reach 7100 MW of installed power through cogeneration by 2011 [51]. This target was later revised with the Action Plan 2005–2007 and the Action Plan 2008–2012, increasing the objective to 10,851 MW by 2020 [52,53].

In February 2004, Directive 2004/8/EC [7] was approved with the aim of promoting and developing high-efficiency CHP. It required Member States to provide a guarantee of the origin of the electricity to demonstrate that it was produced from high-efficiency cogeneration [7]. In 2006, Directive 2006/32/EC on the efficiency of the final use of energy and energy services was published. It required Member States to reduce their energy consumption by at least 9% and expressly indicated cogeneration as one of the possible tools for improving energy efficiency in the industrial sector [54].

The Energy and Efficiency Action Plan 2011–2020 (EEAP 2011–2020) was published in 2011, in accordance with Directive 2006/32/EC. The plan aimed to install 3751 MW in new cogeneration plants by 2020, out of which 2490 MW were planned to be installed between 2011 and 2016 [55]. The ultimate goal was to reach a total of 9807 MW by 2020. In October 2012, the Energy Efficiency Directive 2012/27/EU came into effect, replacing Directives

2004/8/EC and 2006/32/EC. The new directive established rules and obligations to help the EU achieve its 20% energy efficiency target by 2020 [5].

As part of the 'Clean Energy for all Europeans package' released in 2016 [56], an agreement was reached to update the policy framework until 2030 and beyond through the Directive on Energy Efficiency (2018/2002) [6], which amended Directive 2012/27/EU. The key aim was to set a target of at least a 32.5% improvement in energy efficiency by 2030, based on the 2007 modelling projections for the same year. This target is meant to be attained collectively across the EU [6].

In January 2020, Spain's Integrated National Energy and Climate Plan 2021–2030 (INECP) was published, as stated in the 2016 'Clean Energy for All Europeans package' [56]. According to the INECP, the country set a goal to achieve carbon neutrality by the year 2050 and reduce GHGEs by at least 90%, compared to 1990 levels. It also expected a considerable decrease in the installed power of cogeneration, going from an estimated 4373 MW of installed capacity by 2025 to 3670 MW by 2030 [57].

Figure 1 depicts the growth of cogeneration installed capacity in Spain from 1990 to 2020, along with legislative changes. The left side of the graph, shaded in green, represents the pre-liberalization period, before the liberalization of the SES through the enactment of Law 54/1997 [58]. Similarly, the blue area represents the liberalization period. The orange marks depict the targets set by various energy plans, while the blue line indicates the installed power achieved, allowing for a comparison.

Figure 2 shows that from 1991 to 2004, there was significant growth in the CHP installed power, going from 356 MW in 1991 to 5643 MW in 2004. The objective of 2222 MW for the year 2000 set by the PAEE 1991–2000 was vastly exceeded by reaching 4890 MW, which was more than double the initial goal. The PAEE period coexisted with two different regulatory conceptions, the Pre-liberalization and Liberalization period. In the first phase, under Law 82/1980, RD 907/1982 and RD 2366/1994, the installation of CHP went exceptionally well, consistently exceeding the objectives set by the PAEE. In 1997, near the end of the PAEE period, the Spanish liberalization process started. All the previous frameworks were repealed, being the RD 2818/1998 responsible for promoting renewable energy sources and cogeneration. According to the figures, at the beginning of RD 2818/1998, the growth pace of installed CHP capacity (495.5 MW/year, see Figure 2 caption) remained the same. It might be assumed that this was due to the typical 2–3 years between the investment decision and the commissioning of a CHP plant.

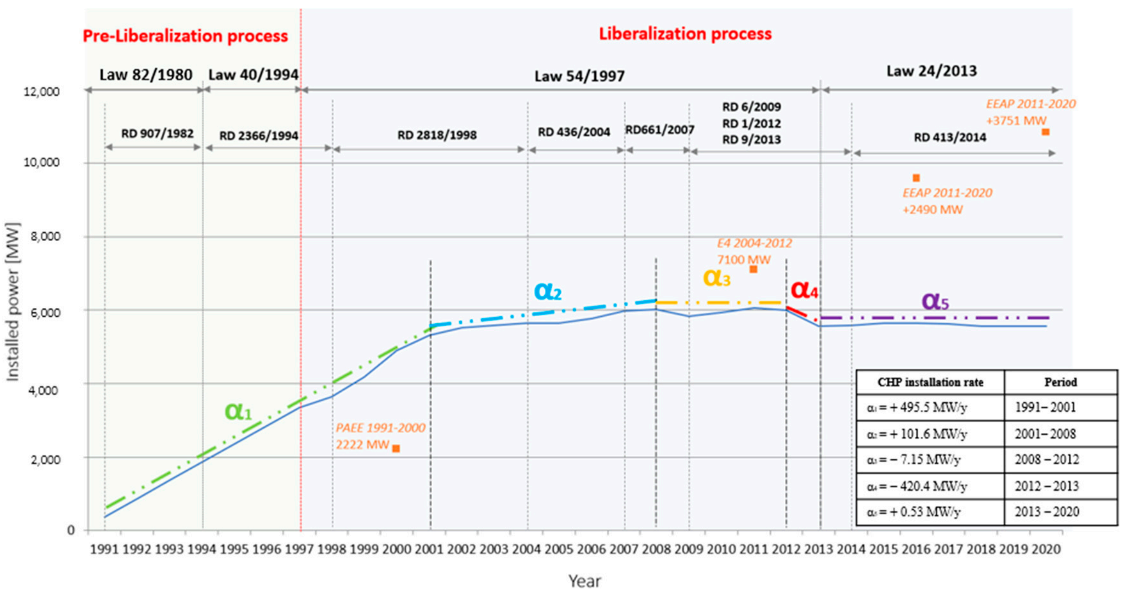

Figure 2. Evolution of the installed CHP in the period 1991–2020. Source: self-elaboration based on [59].

Nevertheless, despite the great variety of RDs addressed to promote CHP plants, from 2001 on, there was a decline in the installed CHP growth speed, changing from 5306 MW in 2001 to only 5989 MW in 2012 (see the lower growth paces at Figure 2 caption). The evolution worsened in 2013 because of a reduction of the installed power, which resulted in a final number of 5568 MW. These numbers more or less remained the same until 2020 with 5572 MW. As a result, the objectives set by E4 and EEAP 2011–2020 of reaching 10,851 MW by 2020 were not fulfilled.

4. A Description of the 1980–2020 Legal–Economic Frameworks for the CHP Plants in Spain

Due to the influence of the regulation on the development of CHP plants in Spain, in the following sections, the main characteristics of the several regulatory frameworks in force in the analysed periods will be described in detail. As a summary, Figure 3 collects the most representative Laws, RDs and directives that influenced the CHP plants through these years. In this regard, Laws are depicted in bold black letters, RDs in black, the energy plans in red and the European directives in blue.

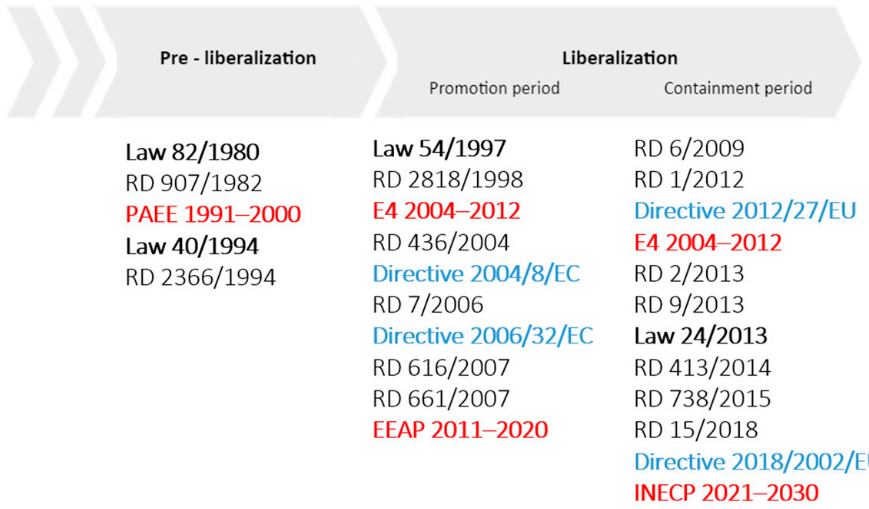

Figure 3. A summary timeline of the regulatory frameworks in Spain in the period 1980–2020. Source: Self-elaboration.

4.1. The Pre-Liberalization Period: 1980–1997

It might be said that the start of the promotion of cogeneration in Spain began with Law 82/1980 on energy conservation. Cogeneration was one of the several technical solutions that could fall within the group of self-producers. As a result, CHP plants were eligible for fiscal benefits defined in the law, as well as for a future and expected economic regime to be developed [42]. This economic regime was lately developed by RD 907/1982 on the promotion of the self-generation (or self-production) of electricity. According to it, the selling prices of the energy of the self-producers to the electricity companies at the point of connection to the network would be established by the Ministry of Industry and Energy [43].The main regulatory characteristics are displayed in Table 1.

In December 1994, Law 40/1994 on the regulation of the national electricity system, which partially modified and repealed Law 82/1980, was enacted. This Law introduced an integrated tariff system for the electrical energy supply, where these tariffs supported all the recognised costs of the different activities of the SES. Energy production was a recognised activity divided into two groups: the ordinary regime and the SR. The SR aimed to back those energy solutions that used renewable energy sources and cogeneration. The Law stated the need for a new economic regime for the SR, which was developed in the same year by RD 2366/1994.

Table 1. Regulatory framework for CHP in the pre-liberalization sub-period 1980–1994. Source: self-elaboration based on [42,43].

Legislation	Main Characteristics
Law 82/1980	
Subject	Established rules, basic principles and incentives to do the following: - Optimize the yields of energy transformation processes; - Strengthen the use of renewable sources; - Promote the use of residual energy from technological processes; - Analyse and control the development of projects for the construction of industrial plants with high energy consumption, according to energy profitability criteria at a national level; - Regulate the relationship between the auto-generators and the electricity distribution companies; - Promote actions to reduce external energy dependence.
Related to CHP installations	The Law defined the self-production or self-generation concept. Those facilities belonging to this concept were described as those whose primary economic purpose was that other than electricity production. Nevertheless, this electricity production was obtained from energy processes using energy excedents. According to it, CHP facilities were embedded into the "*self-producers*" or "*self-generators*" definition.
Key concepts	• Self-generation or self-production; • Surplus of electricity when possible; • Beneficial fiscal framework.
RD 907/1982	
Subject	To promote the self-generation
Related to CHP installations	The RD defined a set of legal conditions to be recognised as a self-producer or self-generator. Among these conditions were those related to facilities whose electricity production was derived from high energy efficiency heat production using conventional fuels or industrial waste heat. Again, according to it, CHP facilities were embedded into the "*self-producers*" or "*self-generators*" definition. Self-producers, or self-generators, were also classified into three categories: off-grid self-generators, grid-connected self-generators and assisted self-generators, which may receive energy from the grid in case of need.
Key concepts	• According to the contractual regime between self-generators and the grid company, the energy surplus was classified as follows: - Guaranteed energy: it required long-term contracts lasting at least two years and included specificities such as maximum and minimum power, day and hour type, etc.; - Scheduled energy: it required a weekly planning program, forecasting the energy throughout the week, including as well maximum and minimum power, day and hour type, etc.; - Eventual energy: it is referred to the non-programmable surpluses that the self-generator might deliver to the grid in case of variations in the electrical demand.

The 1994 new regulatory framework was an inflexion point concerning self-production treatment. Before 1994, the energy conservation approach was based on two great players: renewable energy producers and self-production. The first group was solely formed by hydroelectric power plants equal to or less than 5 MW. It might be inferred that the legislator had no confidence in other renewable energy power plant technologies. The second group was self-production. Those self-producers were energy assets addressed to either energy savings or electricity production through energetic subproducts or waste, which had a specific regulatory framework. After 1994, this clear differentiation was diluted thanks to Law 40/1994 and RD 2366/1994. According to the SR conception, any electricity production under the SR could fall into one of three categories: hydroelectric power plants with a capacity of up to 10 MW, other renewable power plants (including waste) and CHP, as well as electricity producers whose primary economic activity was not electricity production. These categories had a rated power (P) less than or equal to 100 MW.

Nevertheless, although the term "self-generator" or "self-producer" was no longer in the law, its essence was. The new framework allowed both the use of SR-produced energy in their facilities and/or the injection of this energy into the grid. The injected energy into the grid was considered surplus energy, and it was defined as the balance between the injected electricity into the grid and that received from the grid. All interconnection points between the "producer-consumer" facility were considered for this balance. As a result, the term "self-producer" was replaced by the term "producer-consumer", characterized as the owner of a set of energy assets electrically connected to the grid within a facility that has subscribed to an energy supply contract.

The economic framework provided by RD 2366/1994 defined all income and cost streams for CHP plants regarding energy surpluses and consumed energy. As per the framework, CHP plants received revenues for the delivered energy and power while also facing penalties for non-compliance. In addition, distribution companies were forced to acquire the resulting energy surplus. CHP plants were also incentivized to contribute to reactive power regulation. In this regard, the framework enabled potential investors to predict the economic evolution of such energy assets. In Table 2, the main characteristics of these frameworks have been synthesised.

4.2. Liberalization Period: 1997–Ongoing

The liberalization period began in 1997 and represented a radical change for the SES, introducing the concept of free trading in the electricity market. This period has two parts. The first part was the promotion sub-period from 1997 to 2009. As a consequence of several regulatory frameworks, this period was characterized by the sudden growth in installing energy assets related to the SR [39–41]. Paradoxically, CHP was not among the technologies that suffered this outburst. Nevertheless, the resulting rise caused an economic burden on the SES that required containment regulatory measures. As a result, from 2009 to 2020, there was the so-called containment sub-period. Those periods will be discussed in detail below.

4.2.1. Promotion Sub-Period: 1997–2009

The liberalization period began with Law 54/1997 of the SES, which established the principles of a new operating model of the electricity market based on free competition. This law confirmed and preserved the distinction between the ordinary regime and the SR, establishing, for the later, a new remuneration system through the RD 2818/1998 to adapt the SR to the new regulation foreseen by Law 54/1997 [58].

The term "self-producer" appeared again in Law 54/1997. This term was used to refer to an energy production asset that supplied energy to its premises and used, when available, its surplus of energy to feed it into the grid.

It appeared in Article 25, where the exemptions to the energy market were set. According to it, in the case of energy assets under the SR, it allowed these energy assets to avoid the need for their surpluses to be sold in the energy market and for receiving economic remuneration. Additionally, this term was also used in the 8th Transitory Disposition when referring to those energy assets under the former RD 2366/1994.

In 1998, one year later, the definition of "self-production" was provided by RD 2818/1998. According to it, "self-producer" referred to those legal or natural people who generated electricity primarily for their own use. Facilities up to 25 MW had to self-consume at least, on an annual average, 30 per cent of the electrical energy produced, while for facilities equal to or greater than 25 MW, the percentage was at least 50 per cent. Additionally, according to RD, the self-producers' assets could be either CHPs or thermal electricity production facilities unrelated to "electrical activities".

In the same way, RD 2818/1998 also defined the concept of the electricity surplus introduced by Law 54/1997. In this regard, RD forced the SR assets to inject only the surplus into the grid, while the RESs were allowed to inject all their production.

The economic regime to which CHP was subjected changed again in 2004 with RD 436/2004. The new RD did not affect the definitions and conception of the term self-producer besides developing the definition of the self-consumption term. According to RD 436/2004, self-consumption was the electricity supply delivery from CHP to the company's premises or any of the members of a group that owns the installation. In this RD, electricity producers falling under the SR could choose between receiving FIP or FIT, both calculated considering the average electricity tariff (AET) [48].

Table 2. Regulatory framework for CHP in the pre-liberalization sub-period 1994–1997. Source: self-elaboration based on [45,46].

<table>
<tr><th>Legislation</th><th colspan="3">Main Characteristics</th></tr>
<tr><td colspan="4">Law 40/1994</td></tr>
<tr><td>Subject</td><td colspan="3">To regulate activities to guarantee the electricity supply at the lowest cost possible.
Definition of the SR economic framework is to promote RESs and CHP. It is the first time that the definition and recognition of the CHP were stated in the Law.</td></tr>
<tr><td>Related to CHP installations</td><td colspan="3">Facilities that produced electricity through high energy efficiency, including CHP facilities and other non-electric activities with a rated power up to 100 MW, were subjected to the SR under the Law.</td></tr>
<tr><td>Key concepts</td><td colspan="3">• Two different organizational and regulatory systems for the generation and distribution of electricity: integrated system and independent system;
• SR;
• Cogeneration.</td></tr>
<tr><td colspan="4">RD 2366/1994</td></tr>
<tr><td>Subject</td><td colspan="3">On the production of electricity through hydraulic, cogeneration and other installations powered by renewable sources or resources with P≤ 100 MW.</td></tr>
<tr><td>Related to CHP installations</td><td colspan="3">Definition of the economic regime for CHP with $P \leq 100$ MW, which falls into group d (Article 2).
Definition of the necessary requirements for a CHP installation to fall under the SR.</td></tr>
<tr><td>Key concepts</td><td colspan="3">• SR;
• To be registered in the “General Registry of Production Facilities of IDAE Regime (SR) in the General Directorate of Energy of the Ministry of Industry and Energy “;
• Definition of cogeneration.</td></tr>
<tr><td>Classification</td><td colspan="3">Group d</td></tr>
<tr><td rowspan="5">Economic regime</td><td colspan="3">Equation for the calculation of the incomes of the CHP:
$$FT = (PF \cdot Tp + Ec \cdot Te \pm DH \pm ER) \cdot Kf - AI$$
where:
- FT is the income of the CHP;
- PF is the power to bill;
- Tp is the economic term related to the power;
- Ec is the transferred energy;
- Te is the economic term related to the energy;
- DH is a revenue time discrimination;
- ER is a revenue due to the reactive energy;
- Kf is a coefficient specified within the RD 2366/1994;
- AI is a payment for failure to perform.</td></tr>
<tr><td>Rated Power</td><td>Tp [EUR/kW]</td><td>Te [EUR/kWh]</td></tr>
<tr><td>$P \leq 15$ MW</td><td>10.6</td><td>0.0478</td></tr>
<tr><td>15 MW < $P \leq 30$ MW</td><td>10.2</td><td>0.0462</td></tr>
<tr><td>30 MW < $P \leq 100$ MW</td><td>9.9</td><td>0.0448</td></tr>
<tr><td>Further requirements</td><td colspan="3">Compliance with the effective electric efficiency (EEE) in accordance with Annex of this Royal Decree.
Compliance with the efficiency required for the specific installation.</td></tr>
<tr><td>Update</td><td colspan="3">Tp and Te annually updated</td></tr>
<tr><td>Energy supply limits</td><td colspan="3">Only electrical energy in excess of that produced by the facilities under examination may be incorporated into the system.</td></tr>
</table>

In May 2007, the RD 616/2007 [60] was published in response to Directive 2004/8/EC, on the promotion of the cogeneration. In the same year, RD 661/2007 was enacted to regulate the activity of electricity production in the SR while repealing former RD 436/2004. The RD 661/2007 stated an objective method to determine the amount of electricity production from CHP assets and its energy efficiency [49]. This RD incorporated the modifications of the Royal Decree-Law (RDL) 7/2006 [49] concerning abolishing the “self-producer” term in the SES for CHP technologies. In addition, the economic regime of the installations belonging to the SR was again modified.

Table 3 shows the characteristics of the RDs and Laws of the promotion sub-period, while Table 4 provides an outline of the different economic regimes in force for the CHP systems in Spain in the period 1997–2009.

Table 3. Regulatory framework for CHP in the promotion sub-period 1997–2009. Source: self-elaboration based on [47–49,58,60,61].

Legislation	Main Characteristics
Law 54/1997	
Subject	Law that regulated the SES and its activities involved in the electricity supply, i.e., generation, transport, distribution, marketing, and intra-community and international interchanges, as well as the economic and technical management of the electricity system. The production of electrical energy was developed in a regime of free competition. Initially, this regime was based on a system where energy demand and production were fit according to an incipient day-ahead energy market. Later, this incipient market developed into the current electricity market production. The regulatory body of the electricity system was the National Electricity System Commission. This referred to the regulation of the remuneration system of the activities that participated in the supply of electricity. There were also defined in the following ways: - Market operator: responsible for the economic management of the energy market; - System operator: responsible for the technical management of the transport network of the SES; - Definitions of transition costs to competition (TCC).
Related to CHP installations	The Law stated the existence of the SR, defined the technical characteristics of the energy assets under its regime and recognised CHP as one of the technical solutions among them (Article 27). In the initial text, CHP was related to the self-production term, addressed to those that use cogeneration or other forms of electricity production associated with non-electric activities as long as they involve a high energy efficiency with $P \leq 50$ MW. Nevertheless, in 2006, the self-production term was erased from the Law, being the CHP defined as just electricity production energy assets. It also contemplated the maintenance of the former economic scheme for those facilities with rated powers equal to or less than 50 MW, which were installed previously to Law 54/1997 and were under RD 2366/1994.
Key concepts	• Liberalization and free competition; • National Commission of the Electricity System; • Self-producers and electricity producers; • TCC.
RD 2818/1998	
Subject	Promotion of the production of electricity through installations powered by renewable resources, cogeneration or waste. Regulatory development of the SR that was established in Law 54/1997. Establishment of a transitory regime for facilities that, on the date of entry into force of the SES Law, were under RD 2366/1994. Derogation of RD 2366/1994.
Related to CHP installations	Classification of CHP that falls under the SR into groups and subgroups. In particular, CHP plants were included in Group *a*, provided that they had high energy performance and met the requirements of Annex I. They were classified into two groups: - **Subgroup a.1**: Facilities including a cogeneration plant. This refers to systems that combine the production of electricity with the production of useful heat for the subsequent use of non-electric energy; - **Subgroup a.2**: Installations that include a plant using residual energy from any installation, machine or industrial process whose purpose was not the production of electrical energy.

Table 3. *Cont.*

Legislation	Main Characteristics
Key concepts	• SR; • Self-producer plant; • Surplus of electricity; • FIP and FIT.
RD 436/2004	
Subject	Updating, systematization and rewriting of the regulatory regime of the electricity production activity under the SR included in Law 54/1997 of the SES. Establishment of an economic regime for installations covered by the SR based on the AET, regulated by RD 1432/2002. Establishment of two transitory economic regimes: for the installations covered by RD 2366/1994 and for those covered by RD 2818/1998. Derogation of RD 2818/1998.
Related to CHP installations	In particular, CHP was included in category *a* and category *d*: • **Category a**: Self-generating plants using cogeneration or other forms of thermal electricity production related to non-electrical activities with high energy performance and meeting the requirements of Annex I. They were classified into two groups: (a) *Group a.1*: Installations that include a CHP plant. This group was divided into two subgroups: - **Subgroup a.1.1**: CHP that uses NG as a fuel, if it represents at least 95% of the primary energy used, measured by the lower calorific value; - **Subgroup a.1.2**: Rest of CHPs. (b) *Group a.2*: Installations with a plant that uses residual energy from any installation, device or industrial process whose purpose is not the production of electrical energy. • **Category d ***: Installations that use CHP for the treatment and reduction of waste from the agricultural, livestock and service sectors, provided that they entail high energy performance and meet the requirements determined in Annex I, with a maximum installed power of 25 MW. It was divided into three groups: (a) *Group d.1*: Manure treatment and reduction facilities from pig farms in surplus areas; (b) *Group d.2*: Sludge treatment and reduction facilities; (c) *Group d.3*: Other waste treatment and reduction facilities, other than those listed above.
Key concepts	• SR; • Definition of CHP; • Self-producer and self-consumption; • AET; • Electricity Surplus.
RD 7/2006	
Subject	It presented urgent measures in the energy sector. It partially modified Law 54/1997.
Related to CHP installations	Abolition of Sixth (on TCC) and Eighth (on former RD 2366/1994 regulatory framework) transitional provisions of Law 54/1997. The existence of the TCC was a sine qua non condition for the former CHPs to remain adhered to the RD 2366/1994. Subject to the TCC's existence, RD 2818/1998 and RD 436/2004 contemplated in their transitory dispositions the right to preserve the former economic regime for those facilities under RD 2366/1994, with rated powers up to 50 MW. The abolishment of those TCC provisions resulted in the loss of a presumably favourable economic framework into a new framework to come. Nevertheless, some of these changes, such as the abolishment of the former economic framework, were planned to be applied after the revision of the economic framework of the SR, which was undertaken in May of 2007 by RD 661/2007. RD Law 7/2006 also finally erased the self-production term in relation to CHP, being then just considered electricity production assets. This new concept came into force as well, after the revision of RD 661/2007. By Directive 2004/8/EU, it is necessary to adequately remunerate all cogenerated electricity, regardless of the size of the installations.

Table 3. *Cont.*

Legislation	Main Characteristics
Key concepts	• TCC; • Cogenerated energy.
RD 616/2007	
Subject	Creation of a regulatory framework for the promotion of CHP, in accordance with Directive 2004/8/EU. Analysis and evaluation of the national potential for high-efficiency CHP, of the barriers that hinder its development and of the necessary measures to facilitate access to the network of CHP units and small-scale micro-CHP and CHP plants, while defining methods for determining energy savings for high-efficiency CHP units.
Related to CHP installations	Analysis of the application potential of high-efficiency CHP, including high-efficiency micro-CHP, carried out by the Ministry of Industry, Tourism and Trade. List of types of considered high efficiency CHP (Annex I). It is established that the calculation of electricity from CHP must be based on the real relationship between electricity and heat.
Key concepts	• High efficiency electricity
RD 661/2007	
Subject	Establishment of a legal and economic regime for the electricity production activity under a SR that replaced RD 436/2004. Establishment of a temporary economic regime for facilities included in categories (a), (b), (c) and (d) of RD 436/2004. The determination of a premium to complement the remuneration regime for biomass and/or biogas co-combustion facilities in ordinary regime thermal power plants, regardless of their power, in accordance with the provisions of article 30.5 of Law 54/1997. Derogation of RD 436/2004
Related to CHP installations	Classification of CHP plants into categories, groups and subgroups. In particular, cogeneration plants are included in category a. • **Category a**: Producers that use CHP or other forms of electricity production from residual energy. They were classified into two groups: (a) *Group a.1*: Installations including a CHP plant with a high energy efficiency and satisfying the requirements determined in Annex I. This group was divided into four subgroups: - **Subgroup a.1.1**: CHP using NG, representing at least 95% of the primary energy used, or at least 65% of the primary energy used when the rest comes from biomass and/or biogas under the terms provided for in Annex II; - **Subgroup a.1.2**: CHP that used diesel, fuel oil or Liquefied Petroleum Gases (LPG) as fuel (at least 95% of the primary energy used); - **Subgroup a.1.3**: CHP that used biomass and/or biogas as the main fuel, under the terms that appear in Annex II, and provided that this represents at least 90% of the primary energy used, measured by the lower calorific value. The economic regime for this subgroup was defined according to Annex II of this RD and it is based on the fuel used in the plant; - **Subgroup a.1.4**: Rest of CHP that included, as possible fuels to be used, refinery waste gases, coke oven, process fuels, coal and others not contemplated in the previous subgroups. (b) *Group a.2*: Installations using residual energy with no purpose of producing electrical energy.
Key concepts	• SR; • Definition of CHP; • Suppression of the concept of surplus of electricity; • Hourly discrimination regime; • Efficiency Complement.

* For the first time in the regulatory framework of the SR, waste treatment was linked only to CHP technologies to receive its economic benefits. Later, the RD 661/2007 modified this requirement, allowing a wider range of technological solutions.

4.2.2. Containment Sub-Period: 2009–2020

In 2009, the deviation between the income and the regulated costs of the SES was a matter of concern. As a result, containment policies began to be enacted to restrain the regulated costs of the SES. To this end, RDL 6/2009 [62], RDL 1/2012 [63], RDL 2/2013 [64] and RDL 9/2013 [65] were approved. The latter, in particular, clarified the new bases of the economic framework that were yet to come and would affect SR installations [65]. Considering the deficiencies of Law 54/1997 that led to the financial burden of the SES, it was decided to modify the framework of the SES. In light of the above, in December 2013, Law 24/2013 of the SES was approved [66]. This law erased the two economic regimes system, forcing electricity power plants to negotiate in the electricity market. Nevertheless, a specific remuneration regime was applied to those installations that produced electricity through renewable sources, high-efficiency cogeneration and residues [65].

Table 4. Scheme of the different CHP economic regimes in the promotion sub-period 1997–2009. Source: self-elaboration based on [47–49].

<table>
<tr><th>Legislation</th><th colspan="4">Main Characteristics</th></tr>
<tr><td>RD 2818/1998</td><td colspan="4"></td></tr>
<tr><td rowspan="4">Economic regime</td><td colspan="4">Injected electricity price:
$$Price_{i,d,h} = Pm_{i,d,h} + FIP_i \pm ER_i$$
$Price_{i,d,h}$: electricity price to be paid in cEUR/kWh in a particular year *I*, for a day *d*, whithin an hour *h*.
$Pm_{i,d,h}$: electricity market price to be paid in cEUR/kWh in a particular year *i*, for a day *d*, within an hour *h*.
FIP_i: FIP to be paid in cEUR/kWh for the electricity produced in a particular year *i*.
ER_i: reactive energy power complement, stated according to the yearly tariffs, which could be positive if the facility's power factor was 0.9 or higher. Otherwise, it was considered negative.</td></tr>
<tr><td>Rated Power</td><td>FIP [cEUR/kWh] Premium (Pr)</td><td>FIT [cEUR/kWh]</td><td>Time limit</td></tr>
<tr><td>$P \leq 10$ MW</td><td>1.92</td><td>-</td><td>10 years</td></tr>
<tr><td>10 MW < $P \leq 25$ MW</td><td>FIP10 × (40 − P)/30</td><td>-</td><td>Subjected to the existence of the TCC</td></tr>
<tr><td>Further requirements</td><td colspan="4">For both rated powers:
• Justification of the surplus energy given to the electricity grid;
• Compliance with EEE.</td></tr>
<tr><td>Update</td><td colspan="4">Annual update.</td></tr>
<tr><td>Review</td><td colspan="4">Every 4 years.</td></tr>
<tr><td>Energy supply limits</td><td colspan="4">Only electricity surplus could be incorporated into the system.</td></tr>
<tr><td rowspan="2">Facilities under former economic regimes</td><td colspan="4">CHPs with rated powers higher than 50 MW were forced to go to the energy market to sell their energy surpluses. Additionally, there was an additional remuneration of 0.9 cEUR/kWh as a capacity payment concept.</td></tr>
<tr><td colspan="4">CHPs with rated powers equal or up to 50 MW saw their former economic regime granted.</td></tr>
<tr><td>RD 436/2004</td><td colspan="4"></td></tr>
<tr><td></td><td colspan="4">Injected electricity price:
According to RD 436/2004, there were two options for being remunerated. In the first option, the income was based on the injection of the energy produced at a specific FIT.
$$Revenue_{i,d,h} = E_{i,d,h} \times FIT_i + \pm ER_{i,d,h} \times Cer_i$$
$Revenue_{i,d,h}$: obtained income according to FIT scheme to be received in a particular year *i*, for a day *d*, within an hour *h*.
$E_{i,d,h}$: produced electricity injected into the grid in a particular year *I*, for a day *d*, within an hour *h*.
$ER_{i,d,h}$: produced reactive energy injected into the grid in a particular year *i*, for a day *d*, within an hour *h*.
FIT_i: electricity price to be paid in cEUR/kWh in a particular year *i*.
Cer_i: reactive energy complement in a particular year *i*.

In the second option, the income was based on the injection of the energy produced at a specific FIP and the electricity market price:
$$Revenue_{i,d,h} = E_{i,d,h} \times Pm_{i,d,h} + E_{i,d,h} \times FIP_i + E_{i,d,h} \times Inc_i \pm ER_{i,d,h} * Cer_i$$
$Pm_{i,d,h}$: electricity market price to be paid in cEUR/kWh in a particular year *I*, for a day *d*, within an hour *h*.
FIP_i: FIP to be paid in cEUR/kWh for the electricity produced in a particular year *i*.
Inc_i: incentive price offered to participate in the day-ahead energy market to be paid in cEUR/kWh for the electricity produced in a particular year *i*.</td></tr>
</table>

Table 4. *Cont.*

Legislation	Main Characteristics						
	Subgroup a.1.1						
	Rated Power	Incentive [cEUR/kWh]		FIP [cEUR/kWh]		FIT [cEUR/kWh]	
		Incentive	Time limit	Premium	Time limit	Regulated Tariff	Time limit
	$P \leq 1$ MW	-	-	-	-	90% AET	First 10 years
						50% AET	Thereafter
	1 MW < $P \leq 10$ MW	10% AET	First 10 years	30% AET	First 10 years	80% AET	First 10 years
		20% AET	Thereafter	-	Thereafter	50% AET	Thereafter
	10 MW < $P \leq 25$ MW	20% AET	First 15 years	5% AET *	Period I according to the Law 54/1997	55% AET *	Period I according to the Law 54/1997
		15% AET	Thereafter	-	Thereafter	50% AET	Thereafter
Economic regime	25 MW < $P \leq 50$ MW	25% AET	First 20 years	-	-	50% AET	-
		15% AET	Thereafter				
	Subgroup a.1.2						
	Rated Power	Incentive [cEUR/kWh]		FIP [cEUR/kWh]		FIT [cEUR/kWh]	
		Incentive	Time limit	Premium	Time limit	Regulated Tariff	Time limit
	$P \leq 1$ MW	-	-	-	-	90% AET	First 10 years
						50% AET	Thereafter
	1 MW < $P \leq 10$ MW	10% AET	-	30% AET	First 10 years	80% AET	First 10 years
				-	Thereafter	50% AET	Thereafter
	10 MW < $P \leq 25$ MW	10% AET	-	5% AET *	Period I according to the Law 54/1997	55% AET *	Period I according to the Law 54/1997
				-	Thereafter	50% AET	Thereafter
	25 MW < $P \leq 50$ MW	10% AET	-	-	-	50% AET	-

Table 4. *Cont.*

Legislation	Main Characteristics						
	Group a.2						
	Rated Power	Incentive [cEUR/kWh]		FIP [cEUR/kWh]		FIT [cEUR/kWh]	
		Incentive	Time limit	Premium	Time limit	Regulated Tariff	Time limit
	P ≤ 10 MW	5% AET	First 10 years	10% AET	First 10 years	60% AET	First 10 years
		10% AET	Thereafter	-	Thereafter	50% AET	Thereafter
	10 MW < P ≤ 25 MW	5% AET	First 10 years	5% AET *	Period I according to the Law 54/1997	55% AET *	Period I according to the Law 54/1997
		10% AET	Thereafter	-	Thereafter	50% AET	Thereafter
	25 MW < P ≤ 50 MW	5% AET	First 10 years	-	-	50% AET	-
		10% AET	Thereafter				
	Group d.1						
	Rated Power	Incentive [cEUR/kWh]		FIP [cEUR/kWh]		FIT [cEUR/kWh]	
		Incentive	Time limit	Premium	Time limit	Regulated Tariff	Time limit
	-	10% AET	-	20% AET	First 15 years	70% AET	First 15 years
				10% AET	Thereafter	50% AET	Thereafter
	Group d.2						
	Rated Power	Incentive [cEUR/kWh]		FIP [cEUR/kWh]		FIT [cEUR/kWh]	
		Incentive	Time limit	Premium	Time limit	Regulated Tariff	Time limit
	-	10% AET	-	20% AET	First 15 years	70% AET	First 15 years
				10% AET	Thereafter	50% AET	Thereafter
	Group d.3						
	Rated Power	Incentive [cEUR/kWh]		FIP [cEUR/kWh]		FIT [cEUR/kWh]	
		Incentive	Time limit	Premium	Time limit	Regulated Tariff	Time limit
	-	10% AET	-	10% AET	-	60% AET	First 10 years
						50% AET	Thereafter
	* Subjected to the existence of the TCC						

Table 4. *Cont.*

<table>
<tr><th>Legislation</th><th colspan="5">Main Characteristics</th></tr>
<tr><td>Further requirements</td><td colspan="5">For all rated powers and groups, the following is required:
• Justification of the surplus energy given to the electricity grid;
• Compliance with EEE in accordance with Annex I of this Royal Decree. According to the fuel used, this value might vary from 49% to 59%.
Only for group d.1:
• Installations must be submitted annually to the Autonomous Community an environmental audit in which it is explicitly stated the collected amount of pig slurry treated by the facility in the previous year;
• The annual treatment of at least 50% of the amount of pig manure for which the plant was designed must be fulfilled.
Only for group d.2:
• Sludge would be that waste that has the following characteristics:
- Total solids concentration of at least 10,000 parts per million;
- Moisture content between 40% and 99%;
- It can be circulated or pumped, and it can have thixotropic properties.</td></tr>
<tr><td>Update</td><td colspan="5">Annual update for both FIT and FIP and for all rated powers.</td></tr>
<tr><td>Review</td><td colspan="5">For FIT, FIP and incentives of all rated powers and groups, the first revision was expected in 2006. Next, after that, it would be every four years. Nevertheless, when reaching 7100 MW of installed power of group a, these energy assets would see their FIT, FIP and incentives reviewed. For group d, the limit was set at 750 MW of installed power, but the revision would only apply to FIT and FIP.</td></tr>
<tr><td>Energy supply limits</td><td colspan="5">Only electrical energy in excess of that produced by the facilities under examination may be incorporated into the system.</td></tr>
<tr><td>RD 661/2007</td><td colspan="5"></td></tr>
<tr><td></td><td colspan="5">Injected electricity price:
According to RD 661/2007, there were two options for being remunerated. In the first option, the income was based on the injection of the energy produced at a specific FIT.
$$Revenue_{i,d,h} = E_{i,d,h} \times FIT_i + E_{i,d,h} \times 1.1 \times \left[\frac{1}{\mu_{min}} - \frac{1}{\mu_{elec_i}}\right] Cmp_i \pm ER_{i,d,h} \times Cer_i$$
$Revenue_{i,d,h}$: obtained income according to FIT scheme to be received in a particular year i, for a day d, within an hour h.
$E_{i,d,h}$: produced electricity injected into the grid in a particular year i, for a day d, within an hour h.
$ER_{i,d,h}$: produced reactive energy injected into the grid in a particular year i, for a day d, within an hour h.μ_{min}: required minimum electric equivalent efficiency for CHP energy assets.μ_{elec_i}: electric equivalent efficiency for CHP energy assets in a particular year i.
FIT_i: electricity price to be paid in cEUR/kWh in a particular year i.
Cmp_i: efficiency complement indexed to the NG unitary cost, the required minimum electric equivalent efficiency in a particular year i.Cer_i: reactive energy complement in a particular year i.

In the second option, the income was based on the injection of the energy produced at a specific FIP and the electricity market price:
$$Revenue_{i,d,h} = E_{i,d,h} \times Pm_{i,d,h} + E_{i,d,h} \times FIP_i \pm ER_{i,d,h} \times Cer_i$$
$Pm_{i,d,h}$: electricity market price to be paid in cEUR/kWh in a particular year i, for a day d, within an hour h.
FIP_i: FIP to be paid in cEUR/kWh for the electricity produced in a particular year i.</td></tr>
<tr><td rowspan="22">Economic regime</td><td colspan="5">Subgroup a.1.1</td></tr>
<tr><td>Fuel</td><td>Rated Power</td><td>FIP* [cEUR/kWh]</td><td>FIT* [cEUR/kWh]</td><td>Time Limit</td></tr>
<tr><td rowspan="5">NG</td><td>P ≤ 0.5 MW</td><td>-</td><td>12.0400</td><td>-</td></tr>
<tr><td>0.5 MW < P ≤ 1 MW</td><td>-</td><td>9.8800</td><td>-</td></tr>
<tr><td>1 MW < P ≤ 10 MW</td><td>2.7844</td><td>7.7200</td><td>-</td></tr>
<tr><td>10 MW < P ≤ 25 MW</td><td>2.2122</td><td>7.3100</td><td>-</td></tr>
<tr><td>25 MW < P ≤ 50 MW</td><td>1.9147</td><td>6.9200</td><td>-</td></tr>
<tr><td colspan="5">Subgroup a.1.2</td></tr>
<tr><td>Fuel</td><td>Rated Power</td><td>FIP* [cEUR/kWh]</td><td>FIT* [cEUR/kWh]</td><td>Time Limit</td></tr>
<tr><td>Diesel/LPG/Fuel</td><td>P ≤ 0.5 MW</td><td>-</td><td>13.2900</td><td>-</td></tr>
<tr><td rowspan="4">Diesel/LPG</td><td>0.5 MW < P ≤ 1 MW</td><td>-</td><td>11.3100</td><td>-</td></tr>
<tr><td>1 MW < P ≤ 10 MW</td><td>4.6644</td><td>9.5900</td><td>-</td></tr>
<tr><td>10 MW < P ≤ 25 MW</td><td>4.2222</td><td>9.3200</td><td>-</td></tr>
<tr><td>25 MW < P ≤ 50 MW</td><td>3.8242</td><td>8.9900</td><td>-</td></tr>
<tr><td rowspan="4">Fuel</td><td>0.5 MW < P ≤ 1 MW</td><td>-</td><td>10.4100</td><td>-</td></tr>
<tr><td>1 MW < P ≤ 10 MW</td><td>3.8344</td><td>8.7600</td><td>-</td></tr>
<tr><td>10 MW < P ≤ 25 MW</td><td>3.3822</td><td>8.4800</td><td>-</td></tr>
<tr><td>25 MW < P ≤ 50 MW</td><td>2.9942</td><td>8.1500</td><td>-</td></tr>
</table>

Table 4. *Cont.*

Legislation	Main Characteristics				
	Subgroup a.1.3				
	Fuel	Rated Power	FIP* [cEUR/kWh]	FIT* [cEUR/kWh]	Time Limit
	b.6.1: (Agricultural and forest energy crops)	P ≤ 2 MW	11.6608	16.0113	First 15 years
			-	11.8839	Thereafter
		P > 2 MW	10.0964	14.6590	First 15 years
			-	12.3470	Thereafter
	b.6.2: (Waste from agricultural and gardening activities)	P ≤ 2 MW	8.4643	12.7998	First 15 years
			-	8.6294	Thereafter
		P > 2 MW	6.1914	10.7540	First 15 years
			-	8.0660	Thereafter
	b.6.3: (Residues from forest use and forestry operations. Residual biomass produced in any type of treatment or silvicultural use in forest masses)	P ≤ 2 MW	8.4643	12.7998	First 15 years
			-	8.6294	Thereafter
		P > 2 MW	7.2674	11.8294	First 15 years
			-	8.0660	Thereafter
	b.7.1: (Landfill biogas)	-	4.0788	8.2302	First 15 years
			-	6.7040	Thereafter
	b.7.2: (Biogas from anaerobic digestion in a digester of any waste to which anaerobic digestion is applicable)	P ≤ 500 kW	10.0842	13.3474	First 15 years
			-	6.6487	Thereafter
		P > 500 kW	6.1009	9.9598	First 15 years
			-	6.6981	Thereafter
	b.7.3: (Manure by combustion. Liquid biofuels and related by-products)	-	3.0844	5.3600	First 15 years
			-	5.3600	Thereafter
	b.8.1: (Biomass from industrial facilities in the agricultural sector)	P ≤ 2 MW	8.4643	12.7998	First 15 years
			-	8.6294	Thereafter
		P > 2 MW	6.3821	10.9497	First 15 years
			-	8.2128	Thereafter
	b.8.2: (Biomass from industrial facilities in the forestry sector)	P ≤ 2 MW	5.1591	9.4804	First 15 years
			-	6.6506	Thereafter
		P > 2 MW	2.9959	7.1347	First 15 years
			-	7.1347	Thereafter
	b.8.3: (Waste liquids from the paper industry)	P ≤ 2 MW	5.419	9.4804	First 15 years
			-	6.6506	Thereafter
		P > 2 MW	4.9586	9.3000	First 15 years
			-	7.5656	Thereafter

Table 4. *Cont.*

Legislation	Main Characteristics				
	Subgroup a.1.4				
	Fuel	Rated Power	FIP * [cEUR/kWh]	FIT * [cEUR/kWh]	Time Limit
	Coal	P ≤ 10 MW	3.8479	6.1270	-
		10 MW < P ≤ 25 MW	1.5410	4.2123	-
		25 MW < P ≤ 50 MW	0.9901	3.8294	-
	Others	P ≤ 10 MW	1.9332	4.5953	-
		10 MW < P ≤ 25 MW	1.1581	4.2123	-
		25 MW < P ≤ 50 MW	0.6071	3.8294	-
	Group a.2				
	Fuel	Rated Power	FIP * [cEUR/kWh]	FIT * [cEUR/kWh]	Time Limit
	-	P ≤ 10 MW	1.9344	4.6000	-
		10 MW < P ≤ 25 MW	1.1622	4.2100	-
		25 MW < P ≤ 50 MW	0.6142	3.8300	-
	* The values of the different depicted FITs and FIPs were modified in 2008 and 2013 by RD 222/2008 and RD-L 2/2013. In 2008, some FITs for a.1.3 and a.1.4 were increased, while in 2013, all FIPs were dismissed. Nevertheless, all the FITs in place saw their values increase. To provide clarity to the text, the authors have restrained the depiction of their values.				
Further requirements:	For the group a.1: • Compliance with the EEE in accordance with Annex I of this RD. For those installations with P ≤ 1 MW, the minimum EEE required will be 10% lower than that which appears in the table in Annex I, by type of technology and fuel. For the subgroup a.1.3: • Justify the energy that is transferred to the grid by means of each of the fuels used, specifying what is reported in Article 6 of this RD; • Compliance with the EEE in accordance with Annex I of this RD.				
Update	For the subgroup a.1.1: • Quarterly update according to the consumer price index (CPI) and the fuel price index (FPI) (Annex VII); • After a 10-year operating period, an aging correction factor is applied. This factor is not applied to those installations already in operation at the entry in force of this RD. For the subgroup a.1.2: • Quarterly update according to the Annex VII of this RD and the evolution of the CPI and FPI. For the subgroup a.1.3: • Annual update according to the CPI (Article 44). For the subgroup a.1.4: • Annual update according to the evolution of carbon price and/or the CPI, as reported in the Annex VII. For the group a.2: • Annual update according to the CPI.				
Review	Review in 2010 and thereafter every 4 years, for all the groups and subgroups.				
Additional remuneration for SR installations	For installations of the SR, which are required to comply with the EEE: • Efficiency Complement.				

The principles settled in the RDL 9/2013 and in Law 24/2013 would be later developed through the RD 413/2014 [50] to regulate the activity of electricity production through renewable sources, cogeneration and residues. To assign the specific remuneration regime, a standard installation type was associated with each power plant based on its physical and economic characteristics. The legislator performed the classification of those standard installations. It was based on a set of representative parameters calculated in compliance with the principle of an “efficient and well-managed power plant” [64,65]. RD 413/2014 would be partially modified first by RDL 15/2018 and then by RDL 17/2019, due to the simultaneous increase in the cost of emission rights established by the EU and to update the value of reasonable profitability [67,68], respectively.

The regulatory frameworks in force since 2009 are schematically described in Table 5 while in Table 6 the outline of different CHP economic regimes in the cost-containment sub-period is provided.

Table 5. Regulatory framework for CHP in the cost containment sub-period since 2009. Source: self-elaboration based on [50,61–67].

Legislation	Main Characteristics
RDL 6/2009	
Subject	The social bonus is approved, and measures are adopted in the energy sector to do the following: • Establish limits to restrict the increase in the deficit, and define a path for the progressive adequacy of access tolls, also addressing a financing mechanism for the tariff deficit; • Establish additional protection mechanisms for vulnerable groups; • Address the need to free the electricity tariff, as soon as possible, from the burden of financing the activities of the General Radioactive Waste Plan; • Establish a Remuneration Pre-Assignment Register (RPAR) to opt for the remuneration conceived in RD 661/2007 to obtain knowledge on the evolution of SR and gain control of the regulated costs of the SES.
Related to CHP installations	Registration in the RPAR was required to guarantee access to the remuneration established in RD 661/2007. To be enrolled, there must be respected some requirements such as an access point to the grid, construction permit, etc. The facilities registered in the RPAR had a maximum period of thirty-six months from the date of their notification, to be registered definitively in the Administrative Registry of production facilities under the SR. Otherwise, the economic right associated with the inclusion in RPAR would be revoked. They had a period of 30 calendar days from the date of entry into force of this RD to submit their request to the General Directorate for Energy Policy and Mines (GDEPM). Likewise, they had an additional 30 calendar days to deposit the required guarantee and to send the supporting receipt to the GDEPM. Once compliance with the prerequisites of the installation projects was verified, they were registered in the RPAR. The remuneration scheme of RD 661/2007 was subjected to obtaining the power objectives for each one of the technologies under this RD. In case the objectives of one of the technologies were surpassed by the registered power in the RPAR, a new legal-economic framework for these technologies had to be approved.
Key concepts	• Social bonus; • RPAR; • Tariff deficit.
RDL 1/2012	
Subject	Suspension of remuneration pre-allocation procedures and of the economic incentives for new electricity production facilities from cogeneration, renewable energy sources and waste.
Related to CHP installations	The values of the regulated tariffs, premiums and limits provided in RD 661/2007 for new facilities that could be within the scope of the application of this RD were suppressed. The efficiency supplement and the reactive energy supplement, regulated in articles 28 and 29, respectively, of RD 661/2007, were abolished. The government could establish specific economic regimes for certain SR facilities, as well as the right to receive a specific economic regime for those SR facilities with $P \leq 50$ MW. The owners of SR facilities registered in the RPAR who chose not to carry out the execution of the installation, within a maximum period of two months from the entry into force of this RDL, provided that the term for the final registration and sale of energy was not expired, could waive their registration in RPAR, without this implying the execution of the guarantees they had deposited.
Key concepts	Suppression of economic incentives for new facilities under the scope of RD 661/2007.
RDL 2/2013	
Subject	Urgent measures in the electrical system and in the financial sector.
Related to CHP installations	The premiums for cogeneration recognized in RD 661/2007 were cancelled. The tariff applied to subgroup a.1.3 of article 2 of RD 661/2007 was modified, becoming 14.6773 centEUR/kWh, instead of that discussed in article 35 of RD 661/2007, to be received for a maximum period of 15 years from its launch. A new economic index was established to replace the CPI for all of those methodologies that used it for updating the remuneration.

Table 5. *Cont.*

Legislation	Main Characteristics				
	Subgroup a.1.1				
	Fuel	Rated Power	FIP [cEUR/kWh]	FIT [cEUR/kWh]	Time Limit
	NG	P ≤ 0.5 MW	-	12.0400	-
		0.5 MW < P ≤ 1 MW	-	9.8800	-
		1 MW < P ≤ 10 MW	-	7.7200	-
		10 MW < P ≤ 25 MW	-	7.3100	-
		25 MW < P ≤ 50 MW	-	6.9200	-
	Subgroup a.1.2				
	Fuel	Rated Power	FIP [cEUR/kWh]	FIT [cEUR/kWh]	Time Limit
	Diesel/LPG/Fuel	P ≤ 0.5 MW	-	13.2900	-
	Diesel/LPG	0.5 MW < P ≤ 1 MW	-	11.3100	-
		1 MW < P ≤ 10 MW	-	9.5900	-
		10 MW < P ≤ 25 MW	-	9.3200	-
		25 MW < P ≤ 50 MW	-	8.9900	-
	Fuel	0.5 MW < P ≤ 1 MW	-	10.4100	-
		1 MW < P ≤ 10 MW	-	8.7600	-
		10 MW < P ≤ 25 MW	-	8.4800	-
		25 MW < P ≤ 50 MW	-	8.1500	-
	Subgroup a.1.3				
	Fuel	Rated Power	FIP [cEUR/kWh]	FIT [cEUR/kWh]	Time Limit
Economic regime	b.6.1: (Agricultural and forest energy crops)	P ≤ 2 MW	-	16.0113	First 15 years
			-	11.8839	Thereafter
		P > 2 MW	-	14.6590	First 15 years
			-	12.3470	Thereafter
	b.6.2: (Waste from agricultural and gardening activities)	P ≤ 2 MW	-	12.7998	First 15 years
			-	8.6294	Thereafter
		P > 2 MW	-	10.7540	First 15 years
			-	8.0660	Thereafter
	b.6.3: (Residues from forest use and forestry operations. Residual biomass produced in any type of treatment or silvicultural use in forest masses)	P ≤ 2 MW	-	12.7998	First 15 years
			-	8.6294	Thereafter
		P > 2 MW	-	11.8294	First 15 years
			-	8.0660	Thereafter
	b.7.1: (Landfill biogas)	-	-	8.2302	First 15 years
			-	6.7040	Thereafter
	b.7.2: (Biogas from anaerobic digestion in a digester of any waste to which anaerobic digestion is applicable)	P ≤ 500 kW	-	13.3474	First 15 years
			-	6.6487	Thereafter
		P > 500 kW	-	9.9598	First 15 years
			-	6.6981	Thereafter
	b.7.3: (Manure by combustion. Liquid biofuels and related by-products)	-	-	5.3600	First 15 years
			-	5.3600	Thereafter

Table 5. *Cont.*

Legislation	Main Characteristics				
	b.8.1: (Biomass from industrial facilities in the agricultural sector)	P ≤ 2 MW	-	12.7998	First 15 years
			-	8.6294	Thereafter
		P > 2 MW	-	10.9497	First 15 years
			-	8.2128	Thereafter
	b.8.2: (Biomass from industrial facilities in the forestry sector)	P ≤ 2 MW	-	9.4804	First 15 years
			-	6.6506	Thereafter
		P > 2 MW	-	7.1347	First 15 years
			-	7.1347	Thereafter
	b.8.3: (Waste liquids from the paper industry)	P ≤ 2 MW	-	9.4804	First 15 years
			-	6.6506	Thereafter
		P > 2 MW	-	9.3000	First 15 years
			-	7.5656	Thereafter
	Subgroup a.1.4				
	Fuel	Rated Power	FIP [cEUR/kWh]	FIT [cEUR/kWh]	Time Limit
	Coal	P ≤ 10 MW	-	6.1270	-
		10 MW < P ≤ 25 MW	-	4.2123	-
		25 MW < P ≤ 50 MW	-	3.8294	-
	Others	P ≤ 10 MW	-	4.5953	-
		10 MW < P ≤ 25 MW	-	4.2123	-
		25 MW < P ≤ 50 MW	-	3.8294	-
	Group a.2				
	Fuel	Rated Power	FIP [cEUR/kWh]	FIT [cEUR/kWh]	Time Limit
	-	P ≤ 10 MW	-	4.6000	-
		10 MW < P ≤ 25 MW	-	4.2100	-
		25 MW < P ≤ 50 MW	-	3.8300	-
Key concepts	Abolition of FIPs. CPI.				
RDL 9/2013					
Subject	Urgent measures to guarantee the financial stability of the electricity system.				
Related to CHP installations	This RDL empowered the legislator to develop a new economic framework for the former SR facilities under R 661/2007. The new economic framework, or Specific Remuneration framework (SRF), was based on three pillars; namely, the standard value of the initial investment, the standard operating costs and the standard revenues related to the day-ahead energy market. These parameters were set out based on what was called an efficient and well-managed power plant (or installation type), with its specific standard parameters. The value of these parameters was set by the legislator. Repeal of RD 661/2007 and RDL 6/2009. Modification of the Law 54/1997. The Registry of the SRF was created for the granting and adequate follow-up of the SRF. In the registry, there included the remuneration parameters of those facilities, and it was aimed to be a sine qua non condition for being remunerated.				
Key concepts	• SRF; • Installation type.				
Law 24/2013					
Subject	Law that regulates the SES, guaranteeing the electricity supply with the necessary levels of quality and at the lowest possible cost, ensuring the economic and financial sustainability of the system and allowing a level of effective competition in the SES, all within the principles of environmental protection of a modern society.				

Table 5. *Cont.*

Legislation	Main Characteristics
Related to CHP installations	A standard facility was considered, throughout its regulatory useful life and considering an efficient and well-managed company, to determine the investment and exploitation costs of the electrical energy production activity. An SRF was established for electricity production from RESs, high-efficiency cogeneration and waste. CHP facilities were forced to participate in the market, complementing their incomes with a specific regulated remuneration that would allow these technologies to compete on an equal level with the rest of the technologies in the market. This complementary specific remuneration had to be sufficient to reach the minimum level necessary to cover the costs that could not be recovered in the market. It had to allow them to obtain an adequate return concerning the typical installation in each applicable case. The following criteria would modify the remuneration parameters: • In each regulatory period, all the remuneration parameters could be modified, but the regulatory useful life and the standard value of the initial investment; • Every three years, the estimates of income from the sale of generated energy, valued at the production market price, had to be reviewed for the rest of the regulatory period based on the evolution of market prices and forecast of operation hours. Likewise, the remuneration parameters might be adjusted based on the deviations of the market price concerning the estimates made for the previous three-year period. The adjustment method had to be established by regulation and be applicable for the remainder of the useful life of the facility; • At least annually, the values of remuneration for the operation had to be updated for those technologies whose operating costs depend essentially on fuel price. The granting of the SRF had to be established through competitive bidding procedures. The remuneration was based on the criteria that each CHP had their counterpart in a standard facility. For each standard facility, there was a set of remuneration terms, such as: • The remuneration for the electricity sold to the market; • A per unit term of installed power that would cover, when applicable, the investment costs for each standard facility that could not be recovered from the participation in the market; • A remuneration term related to the operation that would cover, if applicable, the difference between the standard operating costs and the income from participation in the production market of said standard facility. The legislator would keep the register of the SRF, which included the remuneration parameters applicable to said facilities. In the regulatory framework that was in charge of the system of energy efficiency obligations derived from the application of Directive 2012/27/UE, programs for the renewal of cogeneration and waste facilities were developed.
Key concepts	• SRF; • Standard facility.
RD 413/2014	
Subject	About the regulation of the legal and economic regime of the activity of electrical energy production from renewable energy sources, cogeneration and waste.
Related to CHP installations	Classification of CHP facilities that fall under RD 413/2014 into categories, groups and subgroups. In particular, CHP falls into category "*a*"; that is, producers that use cogeneration or other forms of electricity production from residual energy. This category was classified in turn into two groups: *Group a.1*: Installations that include a CHP plant. This group is divided into the following subgroups: • **Subgroup a.1.1**: CHPs that use NG as fuel, provided that this accounts for at least 95 percent of the primary energy used, or at least 65 percent of the primary energy used when the rest comes from biomass or biogas from groups b. 6, b.7 and b.8 of Article 2 of RD 413/2014; • **Subgroup a.1.2**: CHPs using petroleum products or coal as the main fuel, provided that it accounts for at least 95 per cent of the primary energy used, measured by the lower calorific value; • **Subgroup a.1.3**: Other CHPs that use NG or derivatives of oil or coal, and do not comply with the consumption limits established for subgroups a.1.1 or a.1.2. *Group a.2*: Installations that include a plant that uses residual energy from any installation, machine or industrial process whose purpose is not the production of electrical energy. CHP plants were also included in groups b.6, b.7 and b.8 of group b, which includes those installations that use as primary energy some non-fossil renewable energies. For the determination of the specific remuneration applicable in each case, each facility, depending on its characteristics, was assigned a standard facility.
Key concepts	• SRF; • Standard facility.
RDL 15/2018	
Subject	Urgent measures for the energy transition and consumer protection.

Table 5. *Cont.*

Legislation	Main Characteristics
Related to CHP installations	It introduced an exemption on the tax imposition of some hydrocarbons used for electricity production in CPH. It introduced the exemption on fees and grid charges for the CHP electricity produced under a self-consumption scheme. It modified the equivalent number of hours of the CHP under the RD 413/2014.
Key concepts	• Energy transition
RDL 17/2019	
Subject	Urgent measures for the necessary adaptation of the remuneration parameters of the electrical system.
Related to CHP installations	It stated the reasonable profitability (7.09%) applicable in the remainder of the regulatory useful life of the standard facilities, which was used to review and update the remuneration parameters during the second regulatory period. It granted the value of the reasonable profitability stated in the first regulatory period for the following two periods. It applied to all CHPs under RD 661/2007 before the appearance of RDL 9/2013.
Key concepts	• Reasonable profitability

Table 6. Scheme of the different CHP economic regimes in the cost-containment sub-period. Source: self-elaboration based on [50].

Legislation	Main Characteristics
RD 413/2014	
Economic regime:	By means of a Ministerial Order (MO), a classification of standard facilities was established based on technology, installed power, age, electrical system, as well as any other segmentations deemed necessary for the former facilities. A code was set for each standard facility defined for this purpose. Each standard facility had a set of remuneration parameters that were calculated assuming an activity carried out by an efficient and well-managed company. The most relevant remuneration parameters necessary for the application of the SRF were, when appropriate, the following: • Investment remuneration by unit power (Rinv); • Operation Remuneration by unit of energy (Ro); • Regulatory life period; • Minimum number of operating hours; • Operating threshold; • Maximum number of operating hours; • Annual upper and lower limits of the market price; • Average annual price of the daily and intraday market. In the lines below, in brief, the revenues concerning the SRF are depicted, avoiding the inherent complexity of this framework. For more details, some recent articles can be checked [39,40]. In this regard, the revenues could be defined as follows: $Revenue_i = Market\_Revenue_i + SRF\_Revenue_i$ $Market\_Revenue_i = \sum_d \sum_h E_{i,d,h} \times Pm_{i,d,h}$ $SRF\_Revenue_i = OP\_R_i + Inv\_R_i$ $E_i = \sum_d \sum_h E_{i,d,h}$ $OP\_R_i = E_i \times Ro_i$ $Inv\_R_i = P_N \times Rinv_i$ $Revenue_i$: obtained revenue according to the SRF to be received within a particular year i. $Market\_Revenue_i$: obtained revenue derived from the participation in the electricity market within a particular year i. $SRF\_Revenue_i$: obtained revenue related to the specific regime remuneration to be received within a particular year i. OP_R_i: operation revenue obtained according to the yearly energy produced within a particular year i and the yearly regulatory parameter *Ro*. Inv_R_i: yearly investment revenue obtained according to the rated power (P_N) of the facility and the yearly regulatory parameter *Rinv*; $E_{i,d,h}$: produced electricity injected into the grid in a particular year i, for a day d, within an hour h. $Pm_{i,d,h}$: market price in a particular year i, for a day d, within an hour h

Table 6. *Cont.*

Legislation	Main Characteristics			
	Classification	Standard facility type	Reasonable return	Regulatory useful life
	Subgroup a.1.1 Subgroup a.1.2 Subgroup a.1.4 Group a.2	Standard installations ranging from IT-01039 to IT-01456	For the first regulatory period it is foreseen: • 7.398% for existing facilities. • Average yield +300 basis points for new facilities for their first 3 months.	25 years
	Subgroup a.1.3	Standard installations ranging from IT-00825 to IT-00935		

5. An Assessment of the 1980–2020 Energy Policy for the CHP Plants in Spain

During the pre-liberalization period, the Spanish government actively promoted the CHP sector to improve energy efficiency and reduce GHGEs using an asset of policies, including tax incentives, grants and favourable tariff structures to encourage its adoption. Consequently, CHP went through significant growth and diffusion in Spain.

The PAEE 1991–2000 targeted an installed power in CHP plants of 2222 MW by 2000 [44]. This goal was overcome with more than 5522 MW installed capacity in 2000, representing a 125% surplus of installed power compared to the expected target.

Among the most significant characteristics of the RDs that defined the economic regime of cogeneration in the pre-liberalization period, the following must be highlighted:

- Energy was rewarded at the consumption price, not the production price, generating favourable sales conditions for self-generators;
- The energy that self-generators could sell to electricity companies was not limited to excess energy alone, as would happen with RD 2818/2018 and RD 436/2004;
- The remunerated energy was paid at a price corresponding to 80% of the average high-voltage tariff;
- The nominal power of the plant was not restricted to specific values to receive benefits from the system, as it would happen with liberalization limiting the rated power up to 50 MW;
- Very advantageous tax and financial incentives boosted the development of the Spanish CHP into the industrial base, such as the chemical, food processing and paper industries.

State institutions played a highly active role in fostering and financing the development and dissemination of CHP in the country during the pre-liberalization period, creating exceptionally favourable conditions for CHP plant installations. Notably, the Institute for the Diversification and Saving of Energy (Instituto para la Diversificación y Ahorro de la Energía, (IDAE)), a public entity attached to the State Secretariat for Energy, exemplified this commitment by supporting industries conducive to CHP installation. This support encompassed the execution of pre-feasibility studies and the supervision of viability studies conducted by specialized engineering teams. The scope of assistance extended to technical and administrative realms, encompassing the management of the inclusion process for the SR [69]. Of note was the significant financial aid extended to businesses for investment, covering up to a substantial 90% of the total investment cost. This robust support framework underscored the proactive engagement of state institutions in catalysing the successful implementation of CHP technologies [70]. As a result, at the end of the pre-liberalization period, many industries decided to take advantage of these conditions, contributing to the successful deployment of CHP in the pre-liberalisation period with installation rates of about 500 MW/year (see Figure 1).

Furthermore, it cannot be ignored that CHP represented a novelty from the point of view of the industrial sector and the State. First, CHP allowed industries to achieve higher energy efficiency and cost savings. Concerning the State's point of view, CHP was a technology that had a set of advantages that allowed the system to do the following:

- Obtain the energy savings objectives;
- Apply these measures within a sector, the industrial sector, that was well known and was used to collaborate with the institutions and manage the required investment funds.

In contrast, the liberalization period was characterized by a clear setback in the spread of CHP, as shown by the set of its different installation rates. Excluding the first $\alpha 1$ installation rate, which is derived from the inertia momentum concerning the former period, the rest of the installation rates were lower (even negative) when compared to the initial one (see Figure 1). The reasons for such a slowdown are varied, and can be found partly in the intrinsic characteristics of this technology and in the developed regulatory framework over the years.

First, in the liberalization period of the SES, CHP had become well established within the industrial sector. Namely, a significant part of the potential user base had already adopted CHP or other alternative technologies, which might have resulted in fewer opportunities for rapid growth than an emerging market.

Second, it is worth highlighting that the liberalization of the SES under Law 54/1997 introduced the electricity market as a new reference element of the SES. The electricity market would be responsible for setting the value of the remuneration for power plants, as well as one of the relevant energy costs for Spanish consumers. In this regard, in terms of the revenue of CHP related to the electricity market prices, the uncertainty concerning the evolution of these prices might have hampered the predictability of the economics of the projects. Additionally, the regulatory scenario led to a new paradigm where the focus on sustainable electricity production included technologies other than CHP, redirecting policies and incentives towards RESs and drawing attention and investment away from CHP. Furthermore, RD 2818/1998 introduced a restriction on the rated power of CHP, limiting its value up to 50 MW. The relevance of this restriction was that it also affected those CHPs that had been installed under the former pre-liberalization regulatory frameworks. This retroactive measure might have affected the risk perception of future investments.

Consequently, all the factors mentioned above might have impacted the resulting value of the $\alpha 2$ installation rate, which, with 101.6 MW/year, was significantly lower than before (see Figure 1).

In 2008, the regulated costs of the SES were higher than expected. The sharp evolution of the installed capacity of some RES technologies resulted in surpassing the power objectives and, consequently, an increase in the scheduled remuneration to be applied to those technologies. Additionally, by this year, the real-estate economic crisis already hit the Spanish economy, worsening the evolution of the SES due to the reduction in the energy demand. In this context, a downward evolution of the parameter $\alpha 3$ took place (see Figure 1). In this period, retroactive regulatory incentives were addressed to contain the regulated costs, mostly applied to photovoltaic systems. In this regard, it is not surprising that in this period, RD 661/2007 was not able to sustain the moderate rate of installation of CHP, as it happened during 2001–2008. Instead, from 2008 to 2012, the rate of installation of CHP ($\alpha 3 = -7.15$ MW/year) was negative, and a set of former CHPs decided to shut down their facilities and end their activity in the SES. As a result, the strategy plan E4 2004–2012 CHP objectives were not achieved by approximately 1000 MW.

In 2012, through RDL 1/2012, the need for a new regulatory scheme in terms of a new electricity law and a new way to remunerate and regulate the RES and CHP was announced. The sole announcement induced a shutdown of 61 CHP facilities, resulting in an installation rate value ($\alpha 4$) of -420.4 MW/year (see Figure 1).

In 2013, the new electricity Law 24/2013 was enacted, along with the regulatory framework to promote RES, CHP and waste RD 413/2014. This brought a new mechanism to remunerate CHP and was applied to new and existing CHP facilities as well. The former CHPs saw a significant impact on their revenue determination. The new remuneration scheme, however, failed to attract the necessary investment into CHP facilities, resulting in an installed capacity of 5616 MW by the end of 2020 (α5 of 0.53 MW/year, see Figure 1). This was far below the 9500 MW capacity objectives set by the E4 2012–2020 energy strategy for CHP.

6. Conclusions

This paper provides an in-depth analysis of the evolution of the CHP policy in Spain from 1980 to 2020, where it can be seen that the development trajectory of CHP in Spain can be segmented into distinct phases, each characterised by changes in regulatory frameworks and economic paradigms.

The first phase, from 1998 to 2008, saw a proactive approach by the Spanish legislator in promoting CHP, creating a stable and favourable regulatory environment. According to this regulatory environment, positive installation rates were achieved for CHP.

The next phase, from 2009 to 2020, was characterised by a completely different approach aimed at containing the SES's costs, which were higher than predicted, mainly due to the unexpected evolution of RESs in the SES. These retroactive measures had a significant impact on the profitability of existing power plants and also on the development of new CHP facilities. As a result, the evolution of the installation of CHPs did not fulfil the Spanish energy objectives.

The research has underlined the importance of the support schemes on the evolution of CHP in Spain. It has also highlighted the impact of the retroactive measures implemented during the cost containment phase on the installation rates.

The analysis reveals a substantial influence of both energy and industrial policies on the CHP sector during the examined period. In the pre-liberalization era, the drive to industrialize the country created an environment conducive to the widespread adoption of CHP. This technology, with its primary application in industrial settings, efficiently met the heat demands of heat-intensive industries, and it yielded numerous benefits, including enhanced efficiency compared to separate production processes, leading to primary energy savings, reduced greenhouse gas emissions, and subsequent cost reductions. The favourable historical–economic conditions were further complemented by a regulatory framework explicitly designed to promote the proliferation of CHP, including generous state incentives and a highly advantageous remuneration system for the electricity generated and sold.

Subsequent observations reveal a shift in the energy policy focus after liberalization, accompanied by corresponding changes in subsequent Laws and Royal Decrees. It is accurate to assert that the emphasis has pivoted towards electricity production systems employing renewable sources. This shift can be attributed, in part, to the influence of European directives and the evolving industrial landscape. Notably, the potential for expanding the installed capacity of CHP systems is more pronounced in environments undergoing industrialization and enhancing energy efficiency in industrial processes than in countries with already established industrial sectors.

Furthermore, the decrease in government investment in the CHP sector and the persistent legislative modifications have heightened uncertainties about the viability of these plants, and this, in turn, has contributed to stagnation in terms of installed CHP, reflected in significantly lower values of α2, α3, α4 and α5, compared to the pre-liberalization α1 value.

An additional significant insight gleaned from the analysis is that, in harmony with EU directives, the Spanish regulatory framework, by incorporating the concept of EEE, places value and compensation in the CHP sector according to the efficiency in generating electricity. This approach, however, overlooks the fundamental origin of this technology, which is designed to fulfil the thermal requirements of heat-intensive processes with superior efficiency compared to conventional systems like boilers.

The analysis of the evolution of CHP in Spain concerning the regulatory scenario undertaken in this paper could be helpful for other countries wishing to develop and promote the CHP sector together with the RES sector. It also highlights the need for regulatory stability to promote investor confidence and the importance of designing robust and adequate support schemes and effective updating mechanisms to ensure the predictability of the economic accounts of renewable assets in the long run.

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Article

The State of Knowledge and Attitudes of the Inhabitants of the Polish Świętokrzyskie Province about Renewable Energy Sources

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Abstract: One of the ways to achieve an energy transformation is to reduce environmental degradation through the use of, among other things, renewable energy sources (RES). The widespread use of RES depends not only on economic and technical aspects, but also on societal acceptance. The aim of this research was to find out the attitudes and the state of knowledge of residents of Świętokrzyskie province regarding RES. This aim was further specified through five research questions. The research used a diagnostic survey method, and respondents' opinions were gathered through an author's survey. This survey included open-ended questions on solar energy (solar panels and photovoltaic panels separately), wind power, hydropower, geothermal energy (ground source heat pump and other sources separately), biomass and biogas. The research sample was selected based on data availability. Econometric modeling was used to analyze the results. The freedom in responding allowed for the exploration of a wide range of respondents' opinions. The results confirmed the positive attitude of residents towards RES and the influence of education level on their self-assessment. Residents of Świętokrzyskie province, in comparison to residents of Poland, stand out for their high level of acceptance of the use of hydropower in their neighborhood. The opinions of the residents of Świętokrzyskie province on the impact of wind power and heat pumps on the environment did not align with the opinions of the residents of Poland.

Keywords: renewable energy sources; surveys; knowledge; environment; social acceptance

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1. Introduction

Poland is obliged to implement Directive 2018/2001 of the European Parliament and of the Council, the main goal of which is to increase the share of renewable energy sources in the EU energy mix to at least 32% by 2030 and for individual member states to achieve so-called total national targets in gross final energy consumption [1]. In Poland, the framework for action on the national energy policy adopted by the Council of Ministers on 2 February 2021 assumes the following [2]:

- increase the share of RES in all sectors and technologies;
- in 2030, the share of RES in gross final energy consumption should be at least 23% with respect to primary energy consumption in 2020, including no less than 32% in electricity (mainly wind and PV) and 28% in heating;
- cover the heating needs of all households by 2040 via system heat and zero- or low-carbon individual sources.

At the same time, further development of photovoltaics, onshore wind farms and the growth of biomass, biogas, geothermal in district heating and heat pumps in individual heating are expected. Distributed energy based on RES power generation will also develop.

By 2030, the number of prosumers is expected to increase about fivefold, and the number of locally sustainable energy areas is expected to increase. There will be increased monitoring in single-family homes and consequences for those responsible for pollution. The energy sector should use waste biomass, in particular, including biodegradable municipal waste, sewage sludge, residues from the agro-food industry and agricultural waste, among others. The use of PV could reach an installed capacity of about 5–7 GW combined in micro and large installations in 2030 and as much as 10–16 GW in 2040. The installation of photovoltaic panels is an alternative to the use of brownfields and poor-quality land, as well as the roofs of buildings, including private ones. The construction of wind power plants is fraught with the risk of social disapproval, generating potential social conflicts [2,3].

In Poland, in 2021, the share of renewable energy in total electricity production was 17% and in Świętokrzyskie province—25.8%. Thus, it is significantly lower compared to Warmińsko-Mazurskie (90.7%), Podlaskie (73.9%) and Pomorskie (60%) provinces [4].

An important factor influencing the development of RES, both in Poland and around the world, is society's attitude to these energy sources. Cases of local communities effectively blocking new RES investments are not uncommon, and residents' reluctance and resistance, along with the NIMBY syndrome, in many cases, prolongs the investment process by up to 7–10 years [5–11].

Public interest in and attitude toward renewable energy sources is one of the key factors in the development and an element of success of the energy transition [12–14]. The level of knowledge about RES, as well as the main motives of individual RES buyers, are important in identifying barriers. Learning about public attitudes, levels of knowledge and even reproduced and perpetuated beliefs can be important in taking action on RES.

Research indicates that residents of Poland have a positive attitude toward RES. Poles expect RES to bring tangible benefits to the average citizen (87%). They perceive RES as the most modern and future-oriented type of energy (82%), capable of ensuring national energy security (76%) and reducing global warming (69%) [15,16]. Poles' positive attitude toward RES is accompanied by a lack of sufficient knowledge about RES [15]. High appreciation for the implementation of RES does not translate into acceptance of these energy solutions in the immediate vicinity [16]. At the same time, public acceptance of RES varies, with 66% accepting offshore wind farms in the Baltic Sea, 75% accepting geothermal sources (i.e., drilling and energy extraction from hot springs) and 76% accepting photovoltaic farms [16].

Poland stands out in comparison to other countries in the region and Europe for its declining population [17]. The 1.7 million increase recorded in the EU in 2022 was not a consequence of Poland's positive population balance. During this time, the population of Poland decreased by 2.4% [18]. Świętokrzyskie province is the region with the lowest natural population growth in Poland. Simultaneously, Świętokrzyskie province is characterized by one of the largest overall migration balances and a dramatically aging population [18,19]. In the context of demographic changes, finding out the current state of knowledge and social acceptance of RES is a tool that facilitates further stimulation of the development of these energy sources. The acceptance of RES by the residents of Świętokrzyskie province, as well as their knowledge of RES, has not been the subject of research and analysis to date. The purpose of this article was to analyze the state of knowledge and attitudes of the residents of Świętokrzyskie province regarding RES and their impact on the environment, human life and health. To achieve the set goal, the following research questions were adopted:

- What is the self-assessment of the respondents regarding their knowledge and utilization of RES?
- What is the awareness of the respondents regarding the necessity of implementing RES?
- What is the awareness of the respondents regarding the impact of RES on the environment?
- Is there acceptance among the respondents for all types of RES in their neighborhood?
- Is there a relationship between the knowledge of the respondents about RES and their level of education?

- Is there a relationship between the knowledge of the respondents about RES and their utilization of RES?

These research questions align with the search for solutions that enable the effective implementation of Poland's energy policy in line with EU priorities.

2. Literature Review

The knowledge and attitudes of residents towards RES are multifaceted [11,20]. A review of the literature has shown that research in this area has been focused on one or at most a few types of renewable energy sources. Most studies did not consider all types of renewable energy simultaneously. Klepacka et al. [21] surveyed owners of passive solar panels in rural areas, with the aim of finding out the importance of selected reasons for households' decisions to participate in a solar panel subsidy program. Meanwhile, Mroczek [22] examined the knowledge of respondents exclusively about wind power. The study by Us et al. [23], despite its focus on self-assessment of knowledge about wind power, solar energy, hydropower, biogas and biofuels, had limited territorial coverage. The respondents were residents of villages in the Lubelskie province [23]. Also, residents of villages who participated in the 2010 conference titled Odnawialne źródła energii dla domu i biznesu [Renewable Energy Sources for Home and Business] were survey participants. The purpose of this research was to determine knowledge and attitudes toward RES. The majority of respondents rated their knowledge as low, with a score of three on a five-point scale. Only one in ten individuals rated it as five. The majority of respondents expressed interest in attending more seminars, workshops and training sessions on RES topics [24].

Surveys on RES knowledge were also conducted as part of an assessment of the ecological awareness of Poles [25]. Although it was a series of surveys carried out in 2008, 2009 and 2010, the set of questions varied and did not always cover topics strictly related to RES [25–27]. Respondents answered closed-ended questions in a telephone survey. One of the questions asked in 2010 was as follows: "With what term do you associate the concept of renewable energy?". Respondents answered "yes", "no" or "hard to say" to 12 statements. Most respondents (85%) indicated that "it is energy based on, for example, solar energy, wind power, wave energy and geothermal energy". 19% of respondents indicated that "it is expensive energy." Respondents also expressed opinions about the type of energy considered the most environmentally friendly. 75% of respondents considered wind power the most environmentally friendly, 63%—hydropower and 61%—solar energy. According to the respondents, the least environmentally friendly were energy sources using biogas (2%), biofuels (5%) and heat pumps (4%). Traditional coal power, gas power and nuclear power were also deemed environmentally unfriendly. Noteworthy is the fact that respondents were characterized by a high consistency of views. 88% of those surveyed who found wind power friendly would agree that wind power plants should be built near their place of residence. A similar percentage of respondents (87%) who considered hydropower environmentally friendly would agree to the construction of a hydroelectric power plant in their neighborhood. Also, there was a high percentage (89%) of respondents who would agree to the construction of a solar energy installation [25]. In addition, the results of this survey showed that the strongest supporters of RES development in Poland were individuals with higher education, aged 35–44 and rural residents. Solar energy elicited the least concern and fear among respondents. Hydroelectric and wind power plants were next in line. In light of the results of this survey, educational efforts regarding RES should primarily target individuals over 54 years of age, women, those with primary education and residents of northern and southeastern Poland [25].

The issue of RES knowledge resonated in closed-ended questions asked in January 2016 to a representative group of Poles [28]. At that time, respondents expressed their opinions on the impact of energy sources/methods of energy production on the climate. Respondents were asked to select one of four given answers: "high carbon dioxide emissions, harmful to the climate", "low carbon dioxide emissions, climate-neutral", "no carbon dioxide emissions, climate-friendly" and "hard to say". Respondents separately assessed the impact of hard coal, brown coal, oil, natural gas, nuclear energy, biofuels, hydro energy, wind energy, solar energy and geothermal energy [28]. However, options for obtaining energy from a source were not included in the above question; for instance, for solar energy, there were no separate questions about solar panels and photovoltaic panels.

From 24 February 2020 to 6 March 2020, a nationwide "Polish Public Opinion Survey on Various Energy Sources" [original title "Badanie opinii Polaków na temat różnych źródeł energii"] was conducted on behalf of the Polish Photovoltaic Association [29]

The survey consisted of 14 closed-ended questions and exclusively focused on two types of RES, i.e., solar energy—ground-based photovoltaic farm and wind power plant and conventional energy sources—nuclear, coal and gas [29]. With such a mix of energy sources, it is not surprising that respondents clearly preferred a ground-based photovoltaic farm [29].

In the majority of the surveys, respondents answered closed-ended questions [23–26,29]. This could potentially distort the results. To eliminate the influence of "predefined" responses, this study adopted the principle that the author's survey would contain only open-ended questions.

3. Characteristics of Świętokrzyskie Province

Świętokrzyskie province is one of the 16 regional units of Poland's administrative division. Świętokrzyskie province consists of 14 counties, including 13 terrestrial counties (covering rural areas and smaller towns) and 1 urban county (Kielce—a city with county rights, which is the capital of the province). Świętokrzyskie province includes 102 municipalities [30].

Świętokrzyskie province has a population of 1.1782 million people, or 3.12% of Poland's population. It is one of the provinces with a smaller population. The average rate of population loss in Świętokrzyskie province, with a value of −0.8% for 2022, was more than double the national average (−0.37%). The population density in Świętokrzyskie province is 100.6 people/km^2, thus lower than the national average (120.8 people/km^2) [18,19]. A total of 46% of the province's population is affected by energy poverty [31]. The land use structure in Świętokrzyskie province is dominated by agricultural land, 64.7%, and forested and wooded land accounts for 28.8% [18,19,32]. Biogas, biomass, solar energy, wind power and hydropower are used in Świętokrzyskie province (Table 1).

Table 1. Types of RES used in industrial installations in Świętokrzyskie province (own elaboration based on [4]).

Type of RES	Biogas	Biomass	Solar Energy	Wind Power	Hydropower
Number of installations	4	4	106	20	17
Total plant capacity, MW	3.8	243.169	98.84	26.462	2.295

4. Methods

Solving the established scientific problem requires conducting sound research, where the selection of appropriate methods, techniques and research tools is crucial. This will allow us to realize the stated goal of this study. The choice in question depends primarily on the people or phenomena that have been subjected to the research procedure. The criteria for selection should be the applicability and effectiveness of the chosen method, as well as its relevance to the concept of the work and the stated research problem [33].

The first step in the implementation of the research process is the selection of the research method, which is the concept of empirical activities. It is defined as "general, insufficiently detailed ways of arriving at reasonable and testable claims about teaching and learning phenomena and processes" [34]. In the concept of A. Kamiński, the research method is "a set of theoretically grounded conceptual and instrumental procedures covering, most generally, the entirety of the researcher's conduct aimed at solving a specific scientific problem" [35]. Hence, the research method is such a research procedure, which is characterized by a well-defined research procedure, along with the use of appropriate research tools. Based on an analysis of the literature, the following research methods can be distinguished [36]: observational method, monographic method, document research methods, scientific experiment methods, expert methods, heuristic method, literature analysis and criticism method, individual case method (so-called case study) and diagnostic survey method, which was used in this research [37,38]. It allowed us to gather knowledge about the structure and directions of the research problem, taking into account the opinions of a specially selected group representing the population for which the research problem in question was carried out. It should be remembered that in order to achieve the highest possible reliability of studies, it is advisable to use several methods in a single study [39].

In the subsequent stage, a research technique was selected. It is defined by A. Kamiński as "practical activities, regulated by carefully worked out directives, allowing obtaining optimally verifiable information, opinions, facts" [40]. M. Łobocki puts it similarly, stating that "research techniques are more closely particularized ways of carrying out the intended research" [34]. Research techniques are subordinate to research methods, play a subservient role and constitute a cognitive activity by means of which the stated objectives can be achieved. The most commonly used research techniques include observation, interviewing, surveying and sociometric techniques.

Next, it is necessary to select a tool with which to conduct the research. It is understood primarily as a way of technically collecting information that comes from research. According to T. Pilch, "a research tool is an object used to implement a selected research technique" [41]. The most important research tools include a survey questionnaire, an observation sheet and a test. The present study used a questionnaire of the author's survey completed by households. It is one of the most common ways of obtaining information, used in surveys of people's opinions and attitudes and in mass surveys. Survey material is collected by gathering responses to a deliberate and predetermined set of questions, aimed at a selected group of respondents, which can be a wide range of people interested in a particular issue [42]. Surveys are also one of the main ways to conduct own studies, as they allow the adaptation of the scope of questions and topics to the author's needs for the research work in progress.

A group of 150 households was surveyed. For the purpose of achieving the goal of this research work, the author's research on the state of knowledge and attitudes of the residents of Świętokrzyskie province about renewable energy sources and their impact on the environment, human life and health was carried out. This research was conducted between 5 June and 31 July 2023. The sample was selected based on data availability. The online survey was conducted on the webankieta.pl platform, which is dedicated to conducting surveys. A diagnostic survey method was used to collect empirical material, which was conducted online. Surveying was adopted as the empirical data collection technique, while the survey questionnaire was the research tool. The author's prepared survey questionnaire was divided into two parts. The first part of the survey concerned the questionnaire proper, i.e., it contained developed sets of questions on the following aspects:

- knowledge of renewable energy sources, directions for their use and the benefits and drawbacks of renewable energy production;
- the relation to renewable energy sources located in the vicinity of the respondent's residence;
- the identification of factors influencing decisions on the choice of energy source at the place of residence;
- the impact of renewable energy production on human health, life and the environment;
- determining the impact of increasing the use of renewable energy sources on the natural environment in Świętokrzyskie province.

The second part is a classic metric that allowed the collection of basic household data, such as gender, age, education, places of residence, occupational situation, total number of people in the household and net income per person in the surveyed household. The selection of the research unit was based on data availability. The research collective was made up of residents of Świętokrzyskie province. After the survey had been conducted, an electronic database was developed. The collected empirical material was subjected to quantitative and qualitative analysis. The results of the study are presented in descriptive and graphical form. They were the basis for the formulation of the final conclusions.

5. Results

5.1. Characteristics of Respondents

150 respondents took part in the survey, of which 54.0% of the total were women (81 people), while 42.67% were men (64 people). 3.33% (5 people) of respondents refused to provide information about their gender. The predominant part of the study population was young people between the ages of 21 and 40 (46.0%; 69 people). A fairly large group was represented by those aged 41–60: 32.0% (48 people). In contrast, the group of 20-year-olds was the least numerous: 2.0% (3 people).

Considering the education of the respondents, the largest group of respondents were those with higher education—70.0% (including higher education with a master's degree—30.0% of the total, higher education with a PhD or higher—26.0% of the respondents and higher education with an engineering/bachelor's degree—14.0% of the total, i.e., respectively, 45, 39 and 21 people). The smallest group was those with basic vocational or trade education—0.67% of the total, or 1 person. General secondary education and vocational education were represented by 28 respondents, or a total of 18.66%. Only 3 people or 2.0% were characterized by primary education.

The largest group among the households were those living in cities with a population of 15,000 or more, i.e., 52.0% of the total respondents (78 people), and rural residents—32.67% (49 people). Only 2 respondents resided in a city with a population of 5000 to 9999, which accounted for 1.33% of the total respondents.

Considering their work situation, 80 respondents indicated employee status (53.33%), and 42 were students (28.0%). The surveyed group included 13 retirees, 9 self-employed and 1 pensioner, who represented, respectively, 8.67%, 6.0% and 0.67% of the total.

In addition, the largest number of people who responded to the survey questions were from four-person households—50 (33.33%) and two- and three-person households—a total of 65 people (43.33%). Respondents constituting households of 5 or more persons accounted for about 15.0% (22 persons). Only 13 respondents said they constituted a single-person household (8.67%).

Respondents in the metric were asked to specify per capita net income. The largest number of surveyed residents of Świętokrzyskie province indicated that their net income per person in the household is between PLN 2501 and PLN 3000—21.33% (32 people). Income above PLN 5000 was indicated by 18.0% (27 people). In contrast, the lowest per capita net income of less than PLN 800 was declared by 6.67% of respondents, i.e., 10 of the total number.

5.2. Knowledge and Attitudes of Residents of Świętokrzyskie Province about RES

In the main part of the questionnaire, respondents were first asked to assess their knowledge of renewable energy sources (Figure 1). Half of the respondents rate the knowledge in question as very good and good, respectively: 14.67% (22 people) and 35.33% (53 people). As many as 53 people assessed their knowledge of RES at a sufficient level, which accounted for 35.33% of those surveyed. 22 households rated their knowledge of RES as poor and very poor, respectively: 16. (10.67%) and 6. (4.0%) of the province's population.

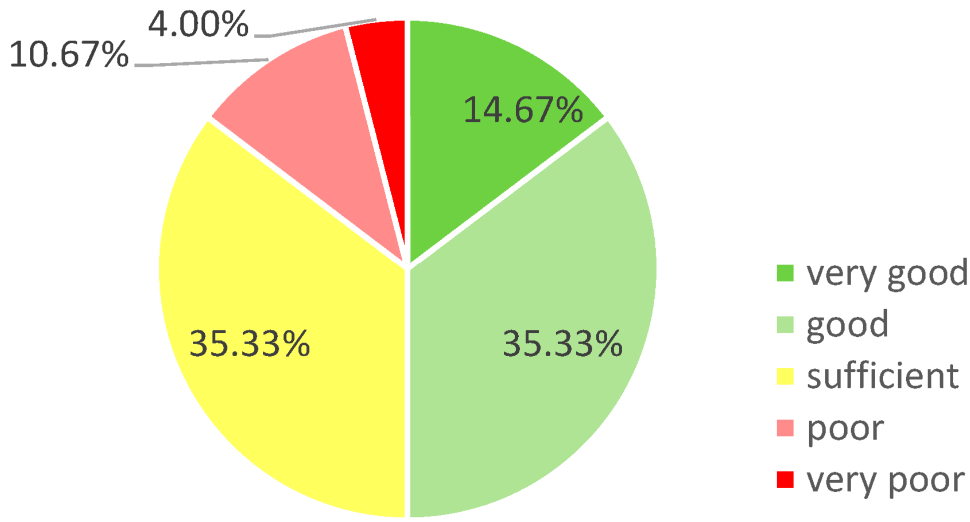

Figure 1. Assessment of households' knowledge of renewable energy sources. Source: own research. N = 150.

36.0% of respondents answered in the affirmative regarding the use of renewable energy sources at their place of residence (54 people), while 64% of respondents do not use RES (96 negative responses; Figure 2). Of the province's residents surveyed, 81.82% use photovoltaic panels, 30.91% use solar panels and 10.91% use ground source heat pumps. A small percentage—9.09%—uses biomass. Respondents do not use water, wind and biogas for energy.

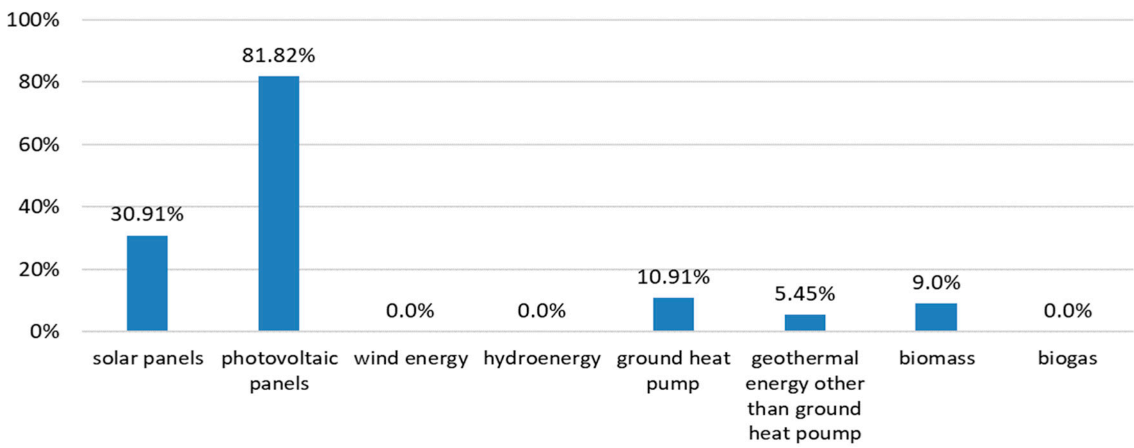

Figure 2. Renewable energy sources used by respondents at their place of residence; possibility to indicate more than one renewable energy source. Source: own research. N = 150.

The 54 people taking part in the survey use RES directly for their own needs. The majority of respondents use RES in single-family buildings (94.44%). 3.7% of respondents use RES in multi-family buildings, and 1.85% in an apartment in a multi-family building. In only two cases did respondents indicate the use of RES in buildings of a different nature, i.e., a commercial and residential building and a service building.

The survey shows that 77.78% of households use RES to obtain electricity, 70.37% to heat hot water, 37.04% for heating and 20.37% for cooling. Seven respondents use RES simultaneously for hot water heating, heating, obtaining electricity and cooling. Ten respondents indicated that they use RES in three manners. In this group of respondents, only three respondents indicated that they use RES to obtain cooling. Eleven respondents indicated that they use RES in two manners.

Respondents indicated that more than 30% of people use RES for heating hot water in single-family, multi-family and other (service and residential, commercial; Figure 3) buildings. The multi-family building is dominated by obtaining energy from renewable sources for electricity generation (66.6%). In apartments, multi-family buildings use RES for heating, obtaining electricity and obtaining cooling at comparable levels (33.3%). The least amount of energy obtained from renewable sources is used in single-family buildings for cooling—about 8.7%.

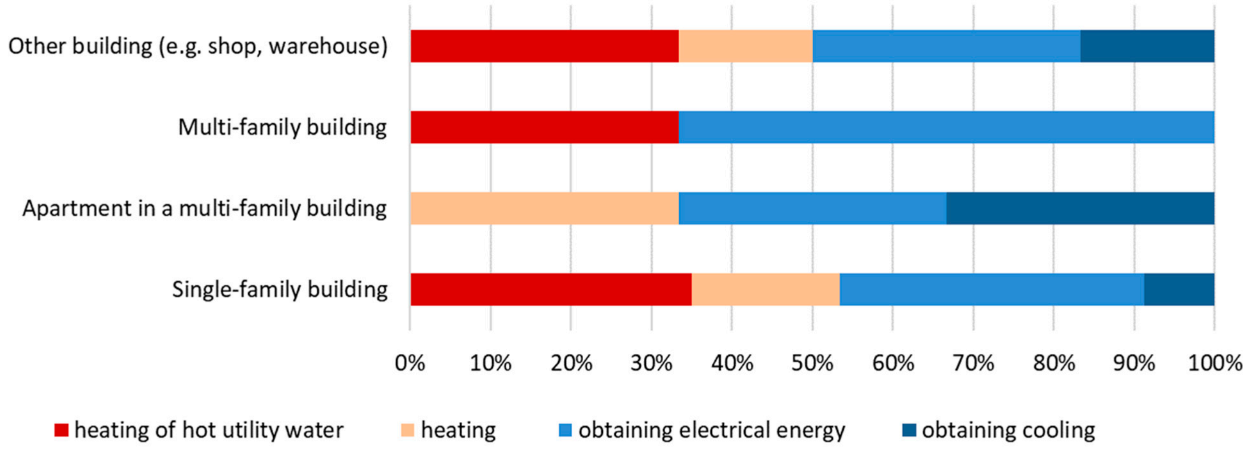

Figure 3. Purpose of RES use vs. nature of building used by respondents. Source: own research. N = 54.

Among the respondents, the vast majority believe that energy production from renewable sources is necessary—a definite yes and a yes were answered by 123 people, which accounted for 82.0% of the respondents (Figure 4). Only 14 people responded negatively to the aspect in question (9.33%). Thirteen respondents had no opinion on the necessity of using RES (8.7%). Respondents indicated various reasons in the surveyed area. They can be grouped as follows:

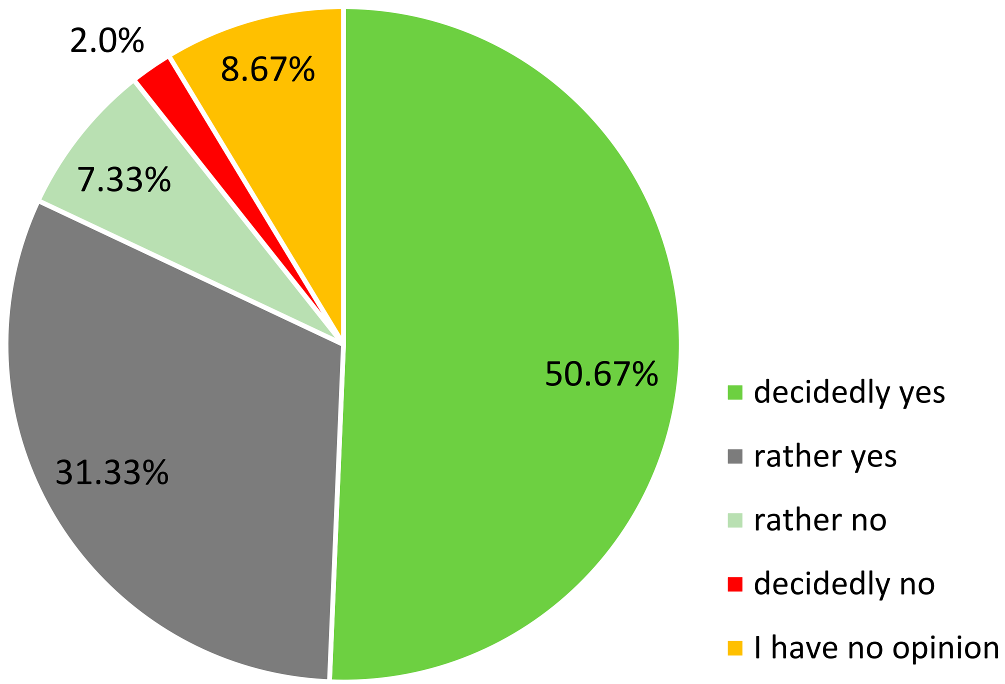

Figure 4. The question of the necessity of renewable energy production according to respondents. Source: own research. N = 150.

- environmental protection (the dominant reason among the responses);
- economic considerations (including cheaper green energy and lower maintenance costs);
- diversification of energy sources and depletion of energy resources (among other things, independence from fossil sources, depletion of non-renewable energy sources, energy security and their use does not involve a deficit),
- other reasons mentioned by respondents (direction of zero emissions and renewable energy sources, saving energy, benefiting the planet and using the potential of the sun, wind and water).

Equally important are the benefits of renewable energy production (Figure 5). The predominant responses include reduced air pollution (76.7%), reduced electricity costs (70.0%), saving other natural resources (58.7%), reduced heating costs (56.0%) and energy independence (54.0%). The smallest number of respondents indicated a benefit in terms of job creation (20.7%). Among other benefits of renewable energy production, one person cited "increased resilience to price fluctuations and energy availability dictated by the global energy lobby" (0.66%). In addition, 2 people responded that they did not know the benefits in question (1.33%).

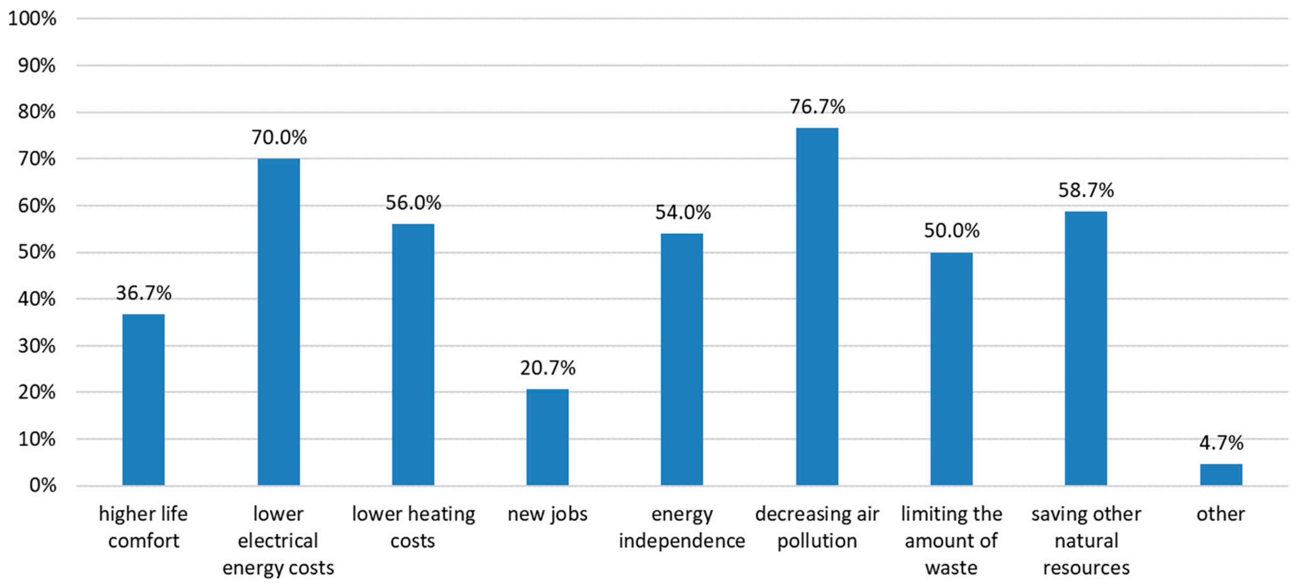

Figure 5. Benefits of renewable energy production; possibility to indicate more than one benefit. Source: own research. N = 150.

As can be seen, more than 60% of respondents say that the location of the renewable energy generation facility in relation to where they live does not matter to them, and they are positive about such an investment (32.0%). 4.67% would think about relocating, and only 2.67% would protest against such an investment. Among the arguments for a positive approach to the RES project were care for the planet, proximity to the workplace, reduced energy costs, opportunities for regional and economic development, reduced environmental pollution, better air quality and cheaper electricity, which could translate into lower prices for products and services, etc.

'In the subsequent question, respondents were asked to indicate the type of RES they disapprove of in the vicinity of their residence (Figure 6). The responses show that a large majority of respondents (55.3%) accept all sources. Significantly fewer respondents disapprove of wind power (24.7%) due to "noise, interference with natural air intake, adverse effects on health in the immediate vicinity and on birds, disfigurement of the landscape, disruption of spatial order, and nuisance to living comfort". A comparable number of respondents—16.7%—disapprove of biomass ("possible odor emissions") and biogas ("possible odor, risk of failure, risk of explosion"). 10% of respondents disapprove of photovoltaic panels due to the inconvenience to living comfort. More than 6.7% of respondents disapprove of ground source heat pumps ("noise"), and 5.3% of respondents disapprove of solar panels (no justification) and hydropower ("noise").

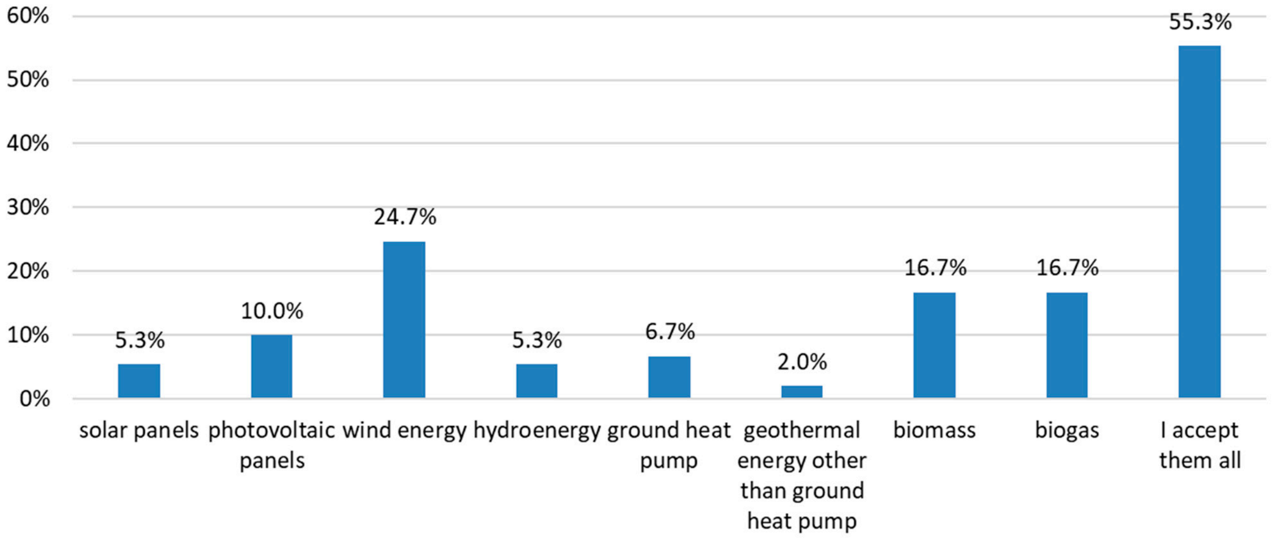

Figure 6. RES not accepted by respondents in the vicinity of their residence. Source: own research. N = 150.

Respondents were asked to identify the disadvantages of renewable energy production. The largest number of respondents cited the disadvantages of using photovoltaic panels and wind power (45.33% each). This was followed by solar panels with 26.67% of respondents, biomass with 24.0% and biogas with 22.67%. The disadvantages of hydroelectric energy and geothermal energy other than ground source heat pump were indicated, respectively, by 16.0% and 10.0%. In contrast, the disadvantages of using ground source heat pumps were identified by 7.33% of respondents—11 people. The disadvantages of obtaining energy from renewable sources as indicated by respondents are shown in Table 2.

Table 2. Disadvantages of renewable energy production indicated by respondents.

Disadvantages of Renewable Energy Production	
Solar panels *: - high installation costs; - high cost of disposal of used panels; - hard-to-treat waste; - possibility of fire; - difficulties in disposal; - too much dependence on weather conditions; - the state is unable to store the energy generated on sunny days and shuts off electricity when there is excessive production; - frequent service; - lack of production during the winter period; - uneven amount of energy extracted depending on the season/day; - mismatch with the power grid.	Photovoltaic panels *: - recycling problem—the need to dispose of used components of RES installations; - interruptions due to low capacity of power lines; - are subject to overheating which consequently carries the risk of fire; - occupation of agricultural land for photovoltaic farms; - panel production involves a heavy burden on the environment; - problems with transmission of excess energy produced; - decrease in the efficiency of the panels after a few years, the rate of their pollution and the lack of collection points for used panels, which consequently leads to environmental pollution; - there is no nighttime energy production or when snow covers them; - overloading of the power grid—urgent modernization of the power grid and energy storage facilities is needed; - decline in performance over time; - threat to animals and harmful to nature; - mismatch with the power grid and voltage spikes.

Table 2. *Cont*.

Disadvantages of Renewable Energy Production	
Wind energy *: - noise generation and danger to birds; - problem of disposing of used components; - there is not always enough wind; - problem with worn propellers, as manufacturers do not disclose what the tripods and propellers are actually made of; - material life; - unstable energy source; - costly source; - landscape degradation; - risk of a turbine fire; - low efficiency; - apparently, there are scientific studies confirming the negative effects of turbines on bees; - drop in land prices in the neighborhood.	Hydropower *: - inundation of inhabited areas and changes in the biosphere; - requires the construction of water reservoirs and flooding of a significant area; - the bang, the noise and the hum of water flowing with high intensity; - the destruction of aquatic ecosystems, reducing their biodiversity; - not everywhere can this system be applied; - few bodies of water and droughts; - declining groundwater levels and low rainfall; - reducing fish populations and regulating the riverbed can lead to the drying up of groundwater and the river itself, as well as the death of marine animals; - water problems; - high installation costs; - high investment costs, long ROI period and negative environmental impact; - small amount of energy in Polish conditions; - requires a water current of sufficient strength; - electromagnetic field; - lack of a fish ladder and too high a water level.
Ground source heat pump *: - high drilling costs; - poor performance; - requires the installation of a horizontal or vertical loop in the ground, which incurs additional costs; the construction of these loops can be time-consuming and expensive, especially in areas with limited accessibility or difficult ground; - the efficiency of a ground heat pump depends on the thermal properties of the ground, such as thermal conductivity and heat capacity; hence, some soils may be unsuitable for efficient heat uptake and transfer, which can affect system performance. - installing a heating loop in the ground can require a significant area; for small plots of land or urban areas where space is limited, it can be difficult to find a suitable place to install a ground source heat pump; - large financial outlay associated with the purchase of a heat pump; - failure rate and numerous fires in the installation.	Geothermal energy other than ground source heat pump *: - high cost of drilling and the uncertainty of its effectiveness; - not everywhere can it be applied; - large expenditures to reach the sources; - requires a lot of exploration; - geothermal sources are not stable (can move) and can only be used in certain locations; - possible contamination of the soil, water and atmosphere with extracted gases and minerals; - poor availability in Poland; - need to drill deep wells.
Biomass *: - possible unpleasant odor; - high investment costs; - low productivity; - biogas plants cannot be built everywhere, costs are high and there is a lack of state aid; - problems with storage, transportation and combustion; - emission of carbon dioxide and other combustion products into the atmosphere. - low energy value;	Biogas *: - unpleasant odor; - methane is a dangerous gas; - low productivity; - high cost of building a biogas plant; - biogas—necessary tightness of the processing plant; - low efficiency (high utilization costs compared to the benefits obtained); - possibility of unsealing the network; - risk of explosion and high cost; - can be intrinsically explosive in nature; care should be taken when storing it.

* Taken from among the responses; those that represented non-response or ignorance of the respondent about the disadvantages of RES types were eliminated. Source: own research. N = 150.

Only 7.33% of respondents gave an affirmative answer to the question of incurring higher energy costs if it came from renewable sources. 52.67% of respondents conditioned their decision on the issue in question on their financial situation. The remaining group, accounting for 40.00%, gave a negative answer.

The most important factors influencing households' decisions to choose an energy source at their place of residence are economic (70.0%) and practical (52.67%; Figure 7). Respondents attribute high importance to ecology and convenience, with 40.0% of respondents giving this response in both cases. In contrast, trend was the least important, indicated by one respondent (0.67%). 48.67% of respondents expressed the opinion that, given a choice in their consumer decisions, they are guided by the source of energy.

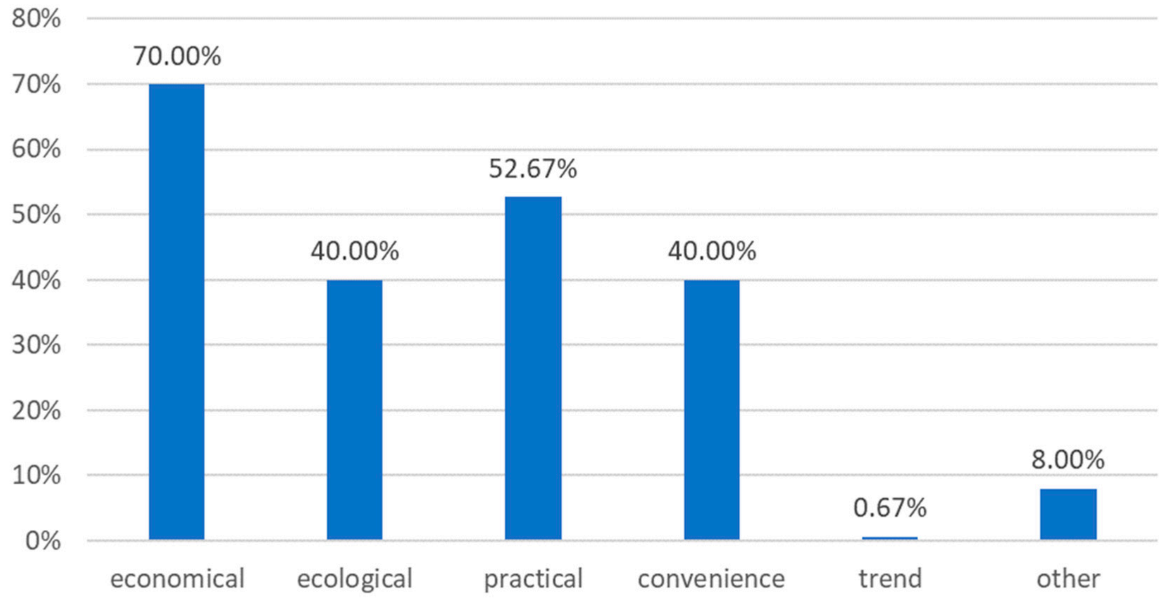

Figure 7. Factors influencing households' decisions to choose an energy source at their place of residence. Source: own research. N = 150.

When asked "If there was a choice of building a renewable energy source in the vicinity of your residence, would you choose from the list?" the largest percentage of people surveyed leaned toward photovoltaic panels—39.33% (59 people; Figure 8). The use of energy from solar panels and ground source heat pumps would be opted for, respectively, by 16.67% and 14.0% of respondents. The fewest respondents would opt for biogas and biomass—0.67% (one person).

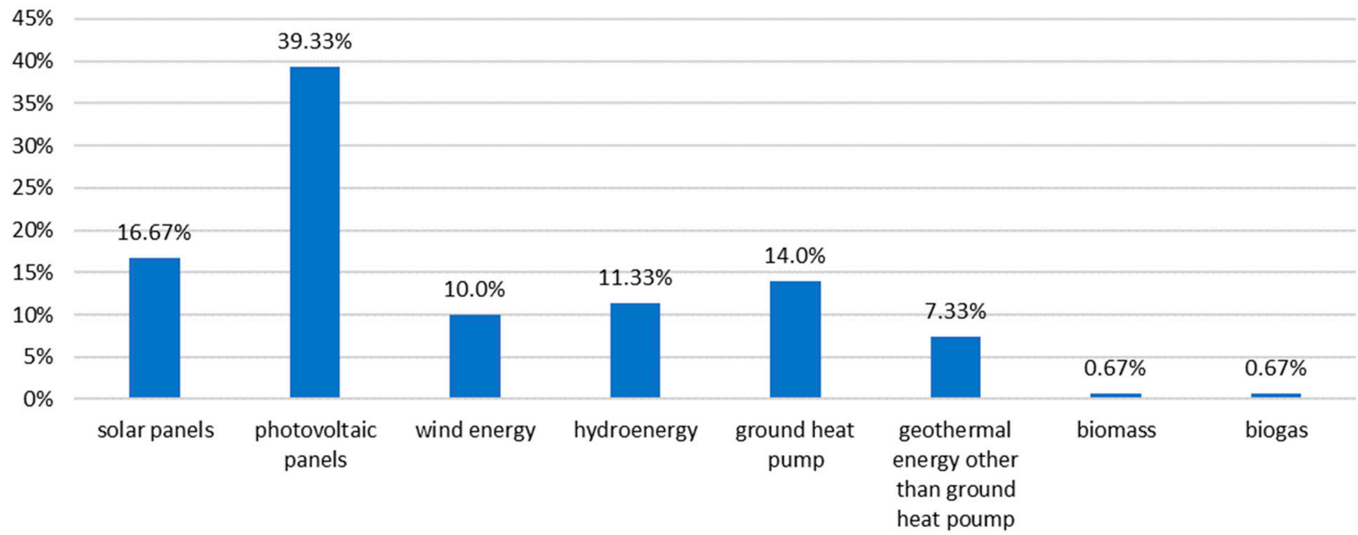

Figure 8. Respondents' choice of a source of renewable energy in the vicinity of their place of residence, if such a possibility existed. Source: own research. N = 150.

Among those surveyed, 95 people said that renewable energy production affects human health and life—63.33%. In contrast, 19 people gave a negative answer (12.67%). In contrast, 36 people surveyed said they did not know whether renewable energy production affects human health and life (24.0%). According to 44 respondents, i.e., 80%, renewable energy production has a positive impact on human health and life (N = 55). The remaining group—11 people (20.0%)—gave a negative answer.

Respondents considered hydropower (52.67%), photovoltaic panels (34.67%), wind power (32.67%), ground source heat pumps (32.67%) and solar panels (31.33%) to be the most environmentally friendly. The least environmentally friendly, according to respondents, are geothermal energy, other than ground heat pump (25.33%), biomass (12.67%) and biogas (6.0%; N = 150).

In turn, respondents identified solar, hydroelectric and geothermal energy as the most efficient sources of renewable energy, with indications, respectively, by 21.19%, 19.87% and 19.21% (N = 150). The least efficient, according to respondents, are wind power (8.61%) and biomass energy (3.31%). 42 people had no opinion on the issue (27.81%).

Hydropower (22.52%), geothermal (19.87%) and solar (14.57%) have the highest reliability, according to respondents. Biomass energy has the lowest reliability (5.3%). 30.46% of respondents had no opinion on the subject (Figure 9).

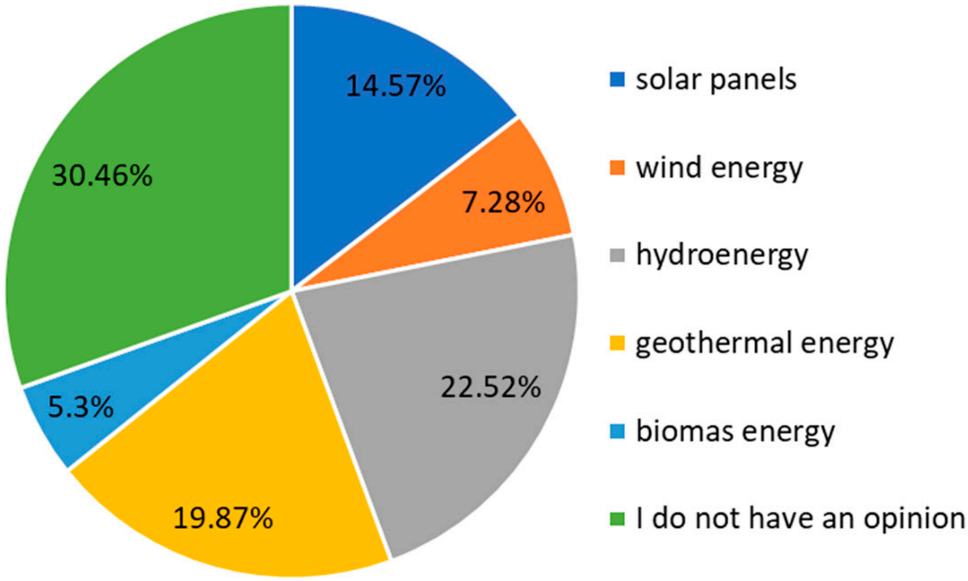

Figure 9. RES considered by survey respondents as the least reliable. Source: own research. N = 150.

There is optimism that, according to 84.11% of respondents, an increase in the use of RES will have a positive impact on the natural environment in Świętokrzyskie province. Only 15.89% of respondents do not see a positive impact of increasing the use of RES on the natural environment in the analyzed province. Consequently, the impact will not only be felt in the studied territorial unit but will also translate to the national level.

Respondents who rated their knowledge of RES as very good and good presented higher education with a master's degree (32.0%; Figure 10). Similarly, respondents with a university degree and a doctorate (or higher) rated their knowledge as very good and good (29.3%). A sufficient level of knowledge is represented by respondents with general secondary education (16.9%). In contrast, those with primary education (16.6%; 1 person), post-secondary or a high-school diploma education (16.6%; 1 person), higher education with an engineering/bachelor's degree (16.6%; 1 person) and higher education with a master's degree (50.0%; 3 people) rated their knowledge in the subject area very poorly. Of the surveyed population, 50.0% rated their knowledge of RES as very good and good, 35.33% rated it as sufficient and 14.6% rated it as poor and very poor.

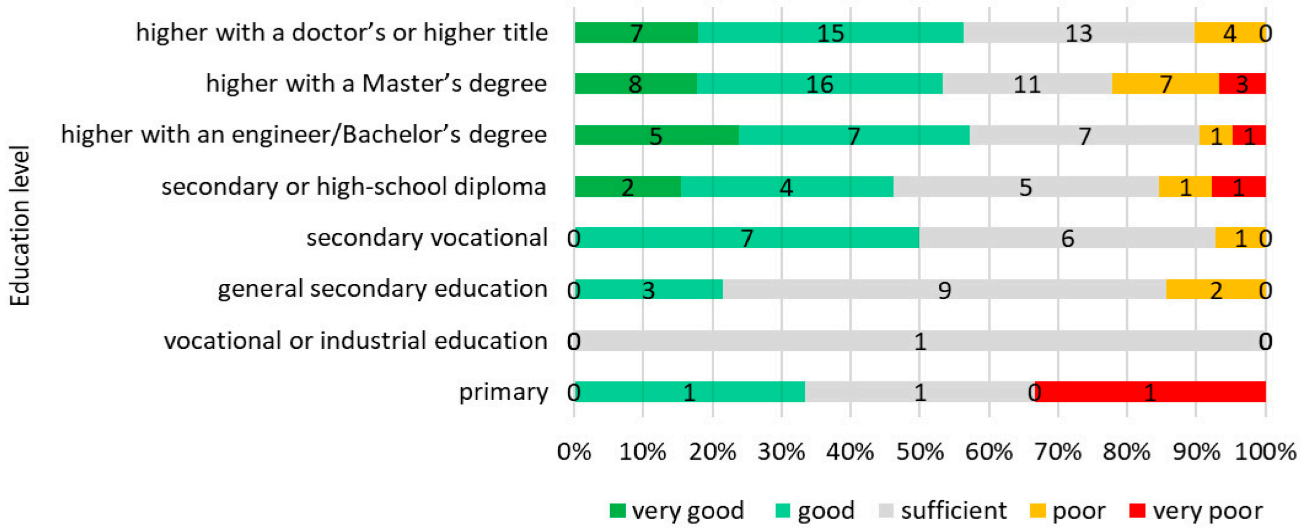

Figure 10. State of knowledge of RES according to respondents' education. Source: own research. N = 150.

In this study, a comparison was made between the respondents' knowledge status and their age (Figure 11). Quite a large group that assessed their knowledge of RES as very good and good were respondents aged 21–40 (45.3%). At the same time, 56.6% in this age group described their knowledge of RES as sufficient. 41.0% of respondents in the 41–60 age range indicated knowledge of RES to be very good, 30.2% to be good, and 68.75% to be poor. In the 60+ age group, the highest percentage of respondents indicated their knowledge of RES to be poor. No one stated that they had very good knowledge in the studied area in the age group <20 years.

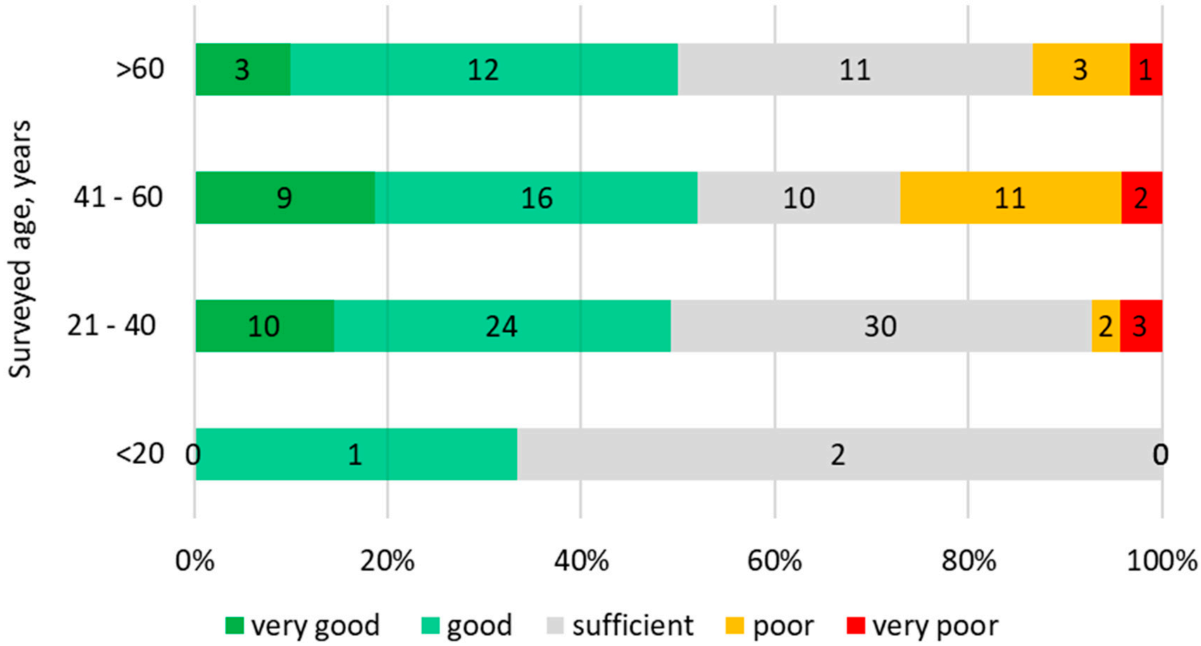

Figure 11. The state of knowledge about RES according to the age of respondents. Source: own research. N = 150.

To complement the scope of analysis based on clustering statistics, an attempt was made to use an econometric model as a research tool. This approach is much more versatile, as it not only involves the evaluation of correlation (coefficient of determination) but also takes into account ANOVA analysis, and its results allow the discovery of cause–effect relationships between the key areas under investigation. An additional aim of the paper is to identify the determinants of the knowledge and attitudes of residents in Świętokrzyskie province regarding renewable energy sources. Table 3 shows the aggregate results of the final forms of the models, where a set of statistically insignificant variables has been removed. Basic statistics characterizing each of the studied relationships have been taken into account, such as the coefficient of determination and significance tests F and t. In Table 3, for the sake of clarity, the following notations have been adopted:

Table 3. Results of econometric modeling.

	Y1	Y2	Y3	Y4	Y5
R2	53.21%	36.19%	46.97%	39.19%	21.30%
F stat.	83.5848	41.6802	65.1114	95.3839	19.8893
Intercept (value)	2.3258	−0.6098	−0.3803	−0.2778	0.1191
(stat. sign. t)	24.9789	−5.2842	−3.7214	−2.6778	0.9657
X3 (value)	0.8892	−0.1841	0.1532		0.2754
(stat. sign. t)	7.8091	−2.3452	2.2036		3.2832
X6 (value)		0.3440	0.2886	0.2979	0.1167
(stat. sign. t)		8.6933	8.2344	9.7665	2.7598
X7 (value)	0.9870				
(stat. sign. t)	8.6933				

Source: own research. N = 150.

- Y1—self-assessed knowledge of respondents;
- Y2—use of RES;
- Y3—awareness of the need for RES;
- Y4—awareness of the positive impact of RES on the environment;
- Y5—acceptance of all types of RES in their surroundings;
- X1—income level;
- X2—place of residence (rural);
- X3—higher education;
- X4—gender;
- X5—age;
- X6—self-assessed state of knowledge of respondents;
- X7—use of RES.

Indicators such as level of knowledge and use of RES were used both as endogenous and exogenous variables. In order to avoid collinearity and an excess number of regressors, only rural residents (in contrast to residents of small and large cities) and people with higher education were included in the model as explanatory variables, as a result of the sparse representation of people with primary and vocational education (which could affect both the approximate collinearity and reduce the model's transparency). It is worth noting that the respondents' state of knowledge was treated as a quantitative variable, which was made possible using a Likert scale. The remaining determinants are dichotomous (binary) variables.

To verify the significance of the parameters, a 5% significance level was assumed, a value commonly used in economic and sociological research. The results proved to be relatively reliable. First of all, it was found that the level of knowledge (in the area of respondents' self-assessment) is statistically significantly influenced by higher education and the use of RES for one's own purposes. This relationship is strong, as it explains 53.21% of the knowledge level. A significantly lower (36.19%) level of explanation characterizes the aspect of respondents' use of renewable energy sources. Factors such as the level of higher education and the respondents' knowledge status in the field of RES have a significant influence here. However, it is worth noting the unique nature of the estimate concerning higher education—individuals with higher education were less inclined to use RES for their own purposes than those with a lower level of education. The third factor for which an attempt was made to determine the influencing determinants was the awareness of the need to introduce renewable energy sources. In this case, the quality of the model turned out to be average, with a coefficient of determination of 46.97% and significant factors such as higher education and the respondents' knowledge status. To assess the factors shaping the awareness of the positive impact of RES on the environment, only the respondents' knowledge status was indicated. The model is characterized by a relatively low level of phenomenon assessment, amounting to 39.19%. However, the lowest coefficient of determination (21.3%) was observed when attempting to explain the factors influencing the acceptance of all types of RES in one's neighborhood. Education level and the respondents' knowledge status were again found to be statistically significant determinants.

6. Discussion

Respondents with a declared low and very low level of knowledge about RES represent a smaller percentage (<15%, Figure 1) than respondents with a lack of information in this area and taking part in surveys conducted in 2010 on a nationwide sample of Polish adults. Then, 16% of respondents indicated that they definitely lacked knowledge about RES. In contrast, 30% of the respondents believed that they mostly lack knowledge about RES [43]. The relative increase in knowledge about RES may be a consequence of the impact of information provided in the media [28] and advertising campaigns, e.g., about the Mój Prąd [44], Czyste Powietrze [45] and Prosument [46] programs.

The knowledge rating depended on the age of the respondents (Figure 11). Respondents between the ages of 21 and 40 declared the greatest knowledge, while those under 20 and over 60 declared the least knowledge. The high and very high self-assessment of knowledge about RES in the first-mentioned age group of respondents is not unusual. According to [25], the youngest people (18–24 years old) who consider themselves the best informed about RES constituted the largest group (68%) of Poles surveyed in 2010. Thus, it can be assumed that these are currently respondents under the age of 40.

The survey shows that respondents with higher education are the largest group with the most declared knowledge of RES (Figure 10). A similar relationship was noted in the results presented by Krzyzanowska et al. [43]. The research results presented in [25] also confirm that the level of education plays an invaluable role in self-assessment of knowledge about RES.

The clear prevalence of photovoltaic panel use by surveyed residents of Świętokrzyskie province (Figure 2) was potentially influenced by local and global factors. Local factors include the implementation of the nationwide Mój Prąd Program starting in 2019. The goal of the Mój Prąd Program is to subsidize expenses related to the purchase and installation of photovoltaic micro-installations [45,47,48]. Global factors, on the other hand, include the ongoing war across the country's eastern border since 2022 and the COVID-19 pandemic [49]. Positive attitudes toward the use of photovoltaic panels and solar panels to produce heat and electricity were already evident in a 2016 survey of a representative sample of Polish residents [28].

Information gaps about RES were demonstrated by respondents taking part in the survey analyzed. When answering open-ended questions, respondents said they had no knowledge of the subject of the question. For example, to the question "why do you think energy production from renewable sources is necessary?" 7.33% of respondents did not provide correct answers. Also, according to the report by [50], Poles have shown low awareness about renewable energy sources.

The high proportion of responses indicating a reduction in air pollution from renewable energy production (Figure 7) is not unique. The aspect of reducing air pollutant emissions through renewable energy production was also pointed out by a majority of surveyed Poles in a 2016 study conducted by the Center for Public Opinion Research [28].

A clear disapproval of living in the vicinity of wind power generation (Figure 8) is a popular attitude among surveyed residents of Świętokrzyskie province. Also, according to [51], 45% of Poles surveyed would not want to live near a wind farm. At the same time, the prevalence of disapproval of wind energy procurement over reluctance to use solar energy is also an attitude of Swiss residents, further influenced by the size of solar and wind installations [52].

Acceptance of the use of hydropower in the neighborhood distinguishes the residents of Świętokrzyskie province compared to the residents of Poland as a whole. According to [25], the percentage of Poles strongly in favor of building hydroelectric power plants (41%) is comparable to those in favor of building wind power plants (39%). In contrast, in Świętokrzyskie province, there are 19% more residents accepting the use of hydropower in their neighborhood compared to those accepting wind power. This attitude is influenced by the fact that there are 17 small hydroelectric power plants in Świętokrzyskie province. The attitudes of the respondents from Świętokrzyskie province about energy costs are in line with those of Poles, who in a survey on the priorities of the European Energy Union, ranked guaranteeing reasonable energy prices first ([5], Figure 10). There is a clear reluctance among Europeans to bear higher heating and food costs as a consequence of rising energy prices. According to [51], this attitude does not depend on the wealth of the state. Disapproval of paying higher costs for renewable energy is also demonstrated by [53] in residents of the UK, US and Australia.

The percentage of the respondents from Świętokrzyskie province ranking wind energy as the most environmentally friendly was significantly lower (32.67%) compared to the respondents taking part in the nationwide survey (75%; [25]). The residents of Świętokrzyskie province also expressed a different opinion from surveyed Poles regarding the environmental friendliness of heat pumps. 32% of the surveyed residents of this province regarded this energy source as environmentally friendly, while only 4% of surveyed Poles shared this view [25]. The significant difference in opinions can be attributed to the increased availability and frequency of heat pump utilization over the past 12 years since the aforementioned survey of Polish residents [54].

From the perspective of the agricultural nature of Świętokrzyskie province, the classification of biomass and biogas (6%) as environmentally friendly energy sources by 12.67% of the residents surveyed is moderately satisfactory, even when compared to the opinion of surveyed Poles, among whom only 2% considered energy utilizing biogas to be environmentally friendly [25].

Asking respondents to indicate the disadvantages of all types of RES in an open-ended question was expedient (Table 2). This ensured that the responses were not influenced by a subjective and confrontational comparison with other sources of energy, such as fossil fuels. The confrontation of RES with nuclear, coal and gas power is noticeable in the research presented by [29].

The freedom in responding allowed for the exploration of a wide range of respondents' opinions (Table 2.). The variety of the drawbacks indicated stems from concerns but also probably from negative personal experiences, especially among users of photovoltaic panels. Over 65% of surveyed users of photovoltaic panels listed one or more disadvantage, both related to photovoltaic panels and other types of RES. Finding out respondents' views on the disadvantages is a valuable resource for decision makers and those undertaking RES-based investments. It serves as the basis for defining the substantive content directed at residents through social communication means to combat stereotypes (e.g., "problem with worn propellers").

The issue of high costs raised by the province's respondents (Table 2) corresponds with the high level of energy poverty among residents [31]. Therefore, it is a signal to decision makers about the justification of continuing and expanding the financial support system for residents to increase the use of RES.

7. Conclusions

The development of RES is one of the ways to achieve the EU's energy policy goals. At the same time, RES are part of sustainable development. Sustainable energy development incorporating RES generates environmental, economic and social benefits. Additionally, environmental concern and efficient resource utilization align with the goals of another economic concept, namely, a circular economy.

The results of this survey indicate a positive attitude of the surveyed residents of Świętokrzyskie province toward RES. Thefavorability for the choice of RES in the vicinity of the residence is clear for solar energy, i.e., solar panels and photovoltaic panels. The aforementioned attitude of respondents is important not only because of the realization of the energy transformation but also because of the tourist and spa nature of Świętokrzyskie province.

Half of the respondents rate their knowledge of RES as very good or good, while the remaining describe their knowledge as sufficient, weak, or very weak. Unfortunately, 64% of the surveyed individuals do not utilize renewable energy sources in their place of residence. Among those using RES, just under 95.0% use it in single-family buildings, including for generating electricity, heating domestic hot water, heating and cooling. The dominant group of surveyed residents of Świętokrzyskie province emphasized the necessity of producing energy from renewable sources, citing reasons such as environmental protection, economic considerations (including cheaper green energy), diversification of energy sources and the depletion of energy resources.

The majority of respondents showed awareness of the disadvantages and limitations of using RES while recognizing their benefits and advantages. At the same time, the majority of respondents indicated the positive impact of RES on people's lives and the environment.

It should be noted that a relationship was observed between the respondents' knowledge and their age and education. The attitudes and knowledge of the surveyed residents of Świętokrzyskie province do not differ from previous results of surveys conducted at the national and regional levels. The econometric model further revealed the leading role of respondents' education and self-assessment of the state of their own knowledge as a factor influencing most endogenous variables. This is in line with expectations and confirms the conclusions drawn from descriptive statistics analysis.

The strength of this study is the results of the research conducted, which can be used to prepare programs and strategies to promote and educate residents about RES. The information obtained from this survey, indicating that a small percentage of respondents consider biomass and biogas to be the most environmentally friendly energy sources, is highly important. It should be a signal to policymakers organizing educational campaigns to include issues of the beneficial environmental impact of biomass and biogas energy. This will help offset the protests and reluctance of residents to new investments using these renewable energy sources, especially considering the agricultural nature of the province, which ensures ample access to resources for energy generation through biological conversion in anaerobic conditions.

In pursuing this research goal, particular attention was paid to the varied responses in relation to the knowledge and attitudes of the respondents regarding RES, especially since respondents were given the freedom to respond in open-ended questions.

The advantage of this study lies in the applied econometric modeling. Identifying the relationships shaping the key research areas addressed in this paper contributes to its cognitive value and further increases the reliability of the estimates confirmed by statistical tests. Another added value of this study is the regional perspective on renewable energy sources. Rational utilization of energy from renewable sources is one of the important components of the sustainable development of the studied province and can bring tangible ecological and energy-related effects in the near future.

Further research may focus on comparing the level of RES development in Poland with other European Union countries. There is also room for in-depth analyses of the impact of RES on the socio-economic development of Polish provinces. In the long-term perspective, the conducted research can be seen as a contribution to existing research and may serve further comparative analyses.

Accessibility to respondents and their willingness to complete the survey on RES was a significant limitation of the completed surveys in terms of the number of surveys returned. There is an unsatisfactory response to some survey questions. Hence, it is reasonable to continue further research in the discussed area, which would include the use of the Likert scale to measure the degree of acceptance of RES by the community of Świętokrzyskie province and the comparison of the level of development of renewable energy in Poland with other European Union countries. There is also room for an in-depth analysis of the impact of RES on the socio-economic development of Polish regions, including Świętokrzyskie province, as they are a factor in its development.

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Valorisation of Waste Heat in Existing and Future District Heating Systems

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Abstract: To recover thermal energy from different sources, its quality and possibilities for utilisation are essential. The wide range of engineering solutions includes a direct connection to the district heating (DH) system and the integration of low-quality heat using heat pumps to increase the temperature level of recoverable heat. Therefore, this article compares waste heat valorisation strategies for integration into existing DH networks, low-temperature DH, and ultra-low heat supply systems using the multi-criteria assessment method. In addition, a local scale assessment was performed to identify the waste heat role in existing RES-based DH systems. The results show that the highest waste heat valorisation rate could be reached when integrated into low-temperature DH systems due to high waste heat potential and suitable temperature conditions. However, a local scale assessment shows a significant impact on the already implemented solar technologies, as waste heat could cover around 70% of the summer heat load.

Keywords: district heating; waste heat; low-temperature heat sources

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1. Introduction

District heating (DH) systems are a necessity in northern and central European countries to move forward sustainable energy systems due to in-place infrastructure, which can be further transformed for integration of renewable energy sources (RESs) and thermal energy storage [1]. In addition, future energy systems require more efficient use of primary energy resources by recovering and utilising unused energy flows [2]. Therefore, DH networks that connect a great number of buildings in urban areas and provide heat for more than half of the city population have significant potential to integrate these recovered heat flows defined as surplus or waste heat [3].

Several studies have shown that integration into DH systems is one of the best solutions for waste heat utilisation [4]. The main reasons are improved efficiency of both the existing heat supply and the waste heat source, lower overall environmental impact due to reduced fuel consumption and avoided thermal flows, and reduced costs from primary energy savings. DH networks can also provide a more flexible heat demand for heat flow utilisation and alignment [5,6]. However, when there is no DH network available at an economically sound distance from the energy source, local heat supply solutions can be analysed by applying energy community solutions with local buildings [7].

1.1. Identification of Waste Heat Sources

The most common waste heat source is industrial objects. Industrial waste heat is divided into three sections based on its temperature—low, medium, and high temperature [8]. Very high-temperature waste heat (above 400 °C) usually arises from combustion processes. The utilisation potential of such very high-temperature heat flows is the highest as it can be used for power generation [9]. Waste heat with temperatures from 100 °C to 400 °C is considered medium-temperature waste heat, and it is part of the exhaust processes [5]. Such temperature levels are suitable for direct integration in DH systems to cover the heat demand. Low-temperature heat or waste heat with a temperature below 100 °C is mostly recovered from cooling processes in industries [10]. During the last decades, research has focused on the utilisation of ultra-low heat sources because innovative integration strategies and operational changes in existing heating networks are necessary to use these heat flows [11].

Heat recovery potential from different industries has been a highly researched strategy for reaching primary energy savings [12–14]. Jauhara et al. [15] reviewed the best practices for various waste heat recovery technologies such as recuperators, regenerators, passive air preheaters, regenerative and recuperative burners, plate heat exchangers and economisers in the steel and iron, food, and ceramic industries. In the research conducted by Denarie et al. [16], industrial waste heat is divided into different temperature levels—high temperature, low temperature, and steam. The authors conclude that in Italy, the main recoverable heat could come from energy production sites and different industrial enterprises. Kasmadakis concluded that the total potential for the implementation of industrial heat pumps (HPs) to recover unused heat flows is 28.37 TWh per year [17].

Boiler houses and combined heat and power plants are excellent waste heat sources for their high-temperature levels [18]. The source of waste heat for CHP plants and boiler houses is flue gases. When a flue gas condenser is not used, then the flue gas temperature can be more than 100 °C and therefore can be used directly with a heat exchanger in the DH network. Nevertheless, it is more useful to use a flue gas condenser for heat recovery in boiler houses and CHPs, especially when the used fuel has a high moisture content, for example, woodchips and biomass. In the case of biomass combustion, a flue gas condenser can increase the boiler efficiency by up to 20% (relating to the lowest heating value) depending on the biomass parameters, design of the boiler, and operating conditions [19].

When a flue gas condenser is used, the leaving flue gases are cooled down to the DH return temperature, which is normally 45–50 °C in the case of a high-temperature DH network. This heat can also be recovered using HPs, as the flue gases can be cooled to 20 °C [20]. This kind of solution is implemented in Tallinn at the Mustamäe CHP plant, where both a flue gas condenser and flue gas HP are installed to recover even more heat. The profitability of this kind of technical solution depends on the capacity of the boiler. Normally, additional heat recovery of the HP in this case can be 4–5% of the total heat.

One of the possible low-temperature waste heat sources is data centres that generate a remarkable amount of heat from electronic equipment—about 97% of that can be used internally or externally for heat load coverage. It is stated that data centres use about 3% of the world's energy consumption, and the used energy amount will only increase in the future [21]. Usually, these centres need constant cooling for proper maintenance, which is an energy-intensive process. Cooling technologies can be supplemented with heat recovery technology to recover the heat generated in these centres and use it internally for space heating or domestic hot water preparation or integrated into the DH network [22]. In this case, for heat recovery, HPs could be used so that all the excess heat would not be emitted into the atmosphere. In data centres, 30–40% of the used energy is from cooling processes, which is a significant amount of energy consumption and one of the criteria to consider using waste heat [23]. This energy in data centres in the liquid cooling system is usually at a temperature from 50 to 60 °C but from air cooling systems, it reaches about 25–35 °C [24]. Another benefit of recovering waste heat, particularly in data centres, is its stable working hours because the cooling system in data centres is needed all the time.

Using sewage water heat in DH with the help of large-scale HPs is an often-used practice, as sewage water is a very good heat source because its temperatures are high enough for HP integration. Normally, when sewage water first arrives at the water treatment plant, the flow temperatures are between 11 and 15 °C during the winter period and above 15 °C during the summer period, which would be excellent for use as a low-temperature heat source for HPs [25]. Still, the wastewater treatment process needs sufficient temperatures for the biological treatment process, so waste heat can be used after the treatment process when the flow temperature is around 9–10 °C.

Sewage water waste heat is highly available as water treatment plants are in most major cities and normally, they are not very far from DH networks [26]. For using treated sewage water as a heat source, the most important parameter in addition to the temperature level is the flow rate, which determines the amount of possible recoverable waste heat. Normally, there are no limiting factors for possible recoverable waste heat by the reservoir where purified sewage is led after treatment. For example, if purified sewage water is led toward the sea after the treatment process, then the purified sewage temperature should be close to the seawater temperature. During the heating period, sewage water temperature is always higher than the seawater temperature, and heat recovery for DH would have a good influence on the marine environment, as the sewage temperature is closer to the seawater temperature.

Although the amount of waste heat from sewage water can be enough to cover a small city's DH demand, this heat source cannot be the main heat source, as the demand and production curves do not match. Heat production from sewage water is quite constant with short periodical fluctuations, so there is not enough heat for the winter period, and a significant amount is left over during the summer period. This can be solved with thermal energy storage or using auxiliary heat sources.

There are many studies dedicated to other types of waste heat and their potential role in heat supply coverage. Escriva et al. [27] investigated heat recovery from refrigerated systems in supermarkets and concluded that useful heat recovered in a UK supermarket could range from 28.7% to 43.2%. A relatively small number of studies are dedicated to heat recovery from electric transformers, which could also be used as a heat source for individual heating or integrated into DH networks [28]. Petrovic et al. [29]. estimated that the theoretical amount of excess heat from power transformers available for DH in Denmark could reach 0.28 TWh per year.

1.2. Methods Used for Waste Heat Potential Estimation

Waste heat integration into the DH system can be divided into indirect and direct integration, which depends on the waste heat temperature and operating temperature of the DH network. Direct waste heat means that it is possible to use it without increasing temperature with a heat exchanger, but when the heat source temperature is too low to use in DH systems, it is necessary to increase the temperature and integrate the heat source indirectly. Therefore, for low-temperature DH systems, HPs are essential elements for the broader integration of waste heat flows [30].

Previous research mostly used bottom-up (surveys) or top-down (estimation) approaches or a combination of both methods for estimating waste heat potential. The bottom-up approach reckons single case study reports and equalises them as a general result. The top-down approach uses general results through already-calculated waste heat potential factors for quantification of waste heat potential. Furthermore, waste heat potential itself is divided into three categories—theoretical, technical, and economical [31].

In the study conducted by Forman et al. [31], global waste heat potential is calculated using the top-down method. In their study, waste heat is part of three types of losses in energy conversion processes—exhaust, effluent, and other losses. The temperature range is also considered. The results show that the largest volume of waste heat is available in low-temperature levels (61% of exhausts and effluents) and most of the waste heat comes from electricity generation.

A study in Taiwan used bottom-up analysis to quantify industrial waste heat potential. In that study, only exhaust flue gas flows are considered [32]. Based on the calculations, the chemical industry has the largest waste heat potential, accounting for 66.5% of total theoretical waste heat potential and 45.8% of technical potential. Exhaust gases with temperatures between 100 and 150 °C have the highest potential in theoretical calculations.

1.3. Waste Heat Integration into DH Networks

Lower-temperature DH systems will allow for utilising low-temperature waste heat sources since those are the most widely available [33]. Previous authors have defined four generations of DH systems and an additional ultra-low DH system concept attributed as a type of fourth-generation DH (4GDH) system or a fifth-generation district heating and cooling (5GDHC) system in some studies [34,35]. The 4GDH system is based on a broader integration of different RES and operations with a low-temperature heat carrier—about 50–70 °C. It reduces the heating network heat losses, expands the energy efficiency of energy conversion technologies [36], and makes it easier to use waste heat in DH systems. The 5GDH concept uses a heat carrier with a temperature close to ambient temperature, which is increased individually at each heat consumer using HPs [37]. The fifth generation [38] DH system differs from others with its combination of heating and cooling systems. Considering, that this generation DH system is based on using different RES, it gives a lot of flexibility when it comes to heating supply—it is possible to use CHP, HPs, solar energy, electric boilers, and others [39]. These DH concepts are also considered smart energy systems that interact with power networks for more efficient use of intermittent RES power [40].

HPs are necessary for low-temperature DH systems and cross-sectoral integration as large electrically powered HPs are used in power-to-heat solutions [41]. What makes this system effective is that it allows for using more renewable energy instead of using fossil fuel, especially in the heat supply. Using HPs can help to smooth the uncontrollable RES electricity production peaks and therefore to stabilise the electricity price and market. Power-to-heat technologies, together with relatively cheaper thermal energy storage [42], allow DH systems to accommodate more intermittent renewable energy than alternatives. However, the whole system is more complicated, and there are more operation conditions that need to be considered, for instance, heat storage. In the event of a significant increase in electricity demand due to power-based heat production [43], additional investments are likely to be required to increase the capacity of the transmission and distribution network. Depending on the waste heat source and previous DH price for consumers, these kinds of investments can still reduce the price for consumers [43]. To make the investments more attractive to DH companies, investment support could be a good option.

1.4. Aim and Scope of This Study

While previous research has explored waste heat potential and the feasibility of heat load coverage, a research gap remains in understanding the conditions necessary for the broader utilisation of waste heat flows, particularly in the context of evolving fourth- and fifth-generation district heating (4GDH and 5GDH) systems and their integration into smart energy systems. Further studies on waste heat's role among different heat supply systems and its potential impact on existing heat supply are necessary. The innovation of this study lies in its pursuit of bridging this gap. The research sets out to explore waste heat's evolving role among various heat supply systems and its potential impact on existing heat supply structures.

Potential waste heat sources are valorised within this study using in-depth national potential assessment and technical simulation. In addition, a local scale waste heat assessment is provided to analyse the potential impact on the existing RES heat supply technologies. This localised analysis is crucial for understanding how waste heat utilisation can complement or potentially impact existing RES systems at the DH system level.

Therefore, this study includes multi-scale analyses by investigating waste heat valorisation for utilisation in DH systems in local and national contexts. Using this approach, the authors aim to provide a comprehensive framework for understanding the potential of waste heat utilisation, not only as an energy source but as a critical component of the evolving energy landscape.

2. Materials and Methods

Within this study, the authors use two approaches for waste heat valorisation assessment—a top-down approach on a national scale and a bottom-up approach for a local urban area. The main steps of the research are shown in Figure 1. A detailed dataset of available waste heat sources and DH networks is collected to perform top-down waste heat potential assessment for utilisation in different types of DH systems. The gathered information is compiled within the main technical parameters of both waste heat sources and integration technologies, for example, temperature regimes of waste heat and heat carriers in DH networks, the necessary amount of power for heat pumps and availability periods, etc. In addition, a multi-criteria assessment method is used to evaluate various impacts on the operation conditions of existing heat supply systems.

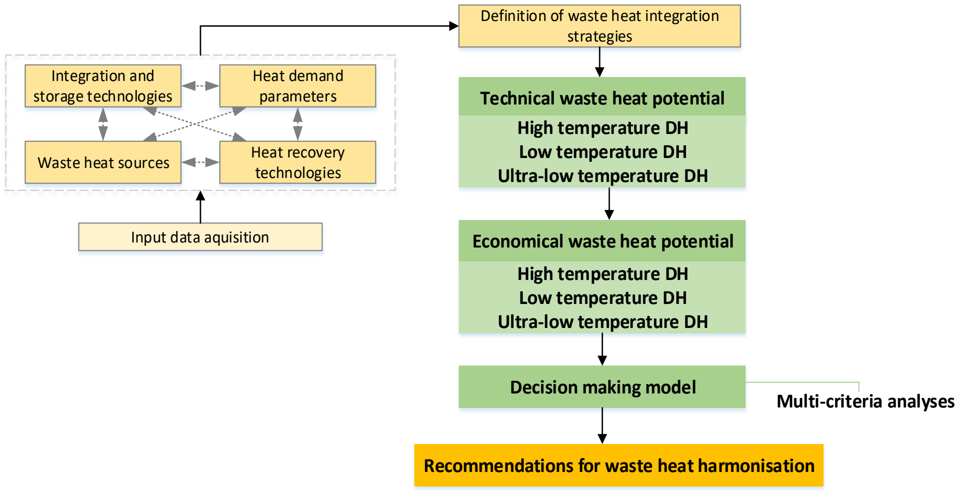

Figure 1. Main research steps.

Further, local-scale waste heat potential analyses are performed to develop a decision-making model for the integration of waste heat sources. Several criteria, including primary energy savings and specific investment costs, are gathered in the decision-making model to compare different waste heat sources from the perspective of the DH operator.

2.1. Top-Down Approach for Waste Heat Valorisation

This study includes the main waste heat sources indicated in Figure 2 and analyses their possible integration into different DH system types. The analysed waste heat sources include existing power and heat generation units (CHP and boiler houses), industrial enterprises, data centres, the largest retail centres, electric transformers, and wastewater treatment plants. Future studies could also include a waste heat assessment from cooling and refrigeration processes in cold warehouses and other service and residential buildings. Also, metro stations are not included as potential heat sources because such infrastructure does not exist in Latvia.

For the national scale assessment, three different types of existing and future DH systems are analysed as heat sinks for waste heat utilisation. First, the waste heat integration into existing heat supply systems (defined as a high-temperature DH system) is investigated. In addition, two future development heat supply systems are compared—low-temperature DH and ultra-low DH systems (representing the 5GDHC concept). The main assumed parameters for the heat supply systems are shown in Figure 2.

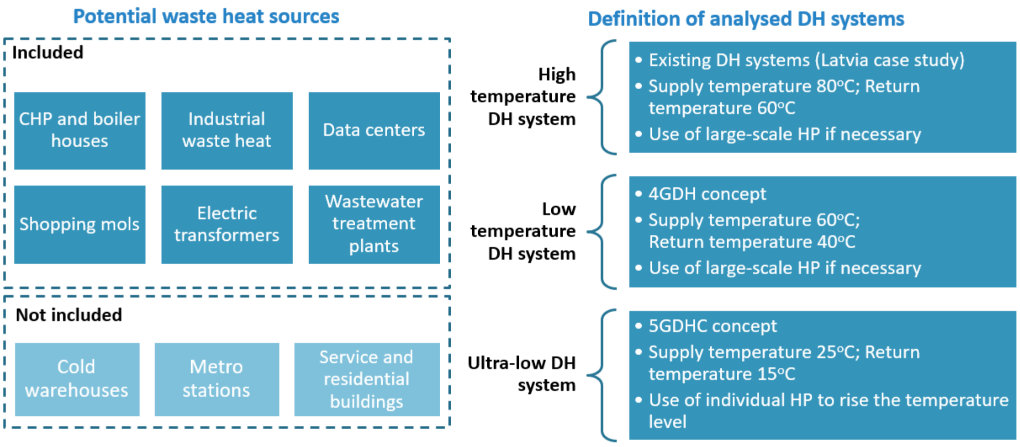

Figure 2. Research boundaries.

Table 1 lists the potential heat recovery technologies assumed for waste heat integration—direct heat recovery using heat exchangers and flue gas condensers and indirect heat recovery with air or water HPs. Direct heat recovery would be possible only for high-temperature waste heat from industrial sites and energy facilities.

Table 1. Overview of analysed waste heat sources [44].

Waste Heat Source	Process for Recovery	Temperature Level	Existing DH Network	Low-Temperature DH	Ultra-Low DH System
CHP and boiler houses	Heat recovery from flue gases	70–100 °C	Flue gas condenser	Heat exchanger	Not suitable
	Deep cooling of flue gases	40–70 °C	HP	Heat exchanger	Heat exchanger
Industrial waste heat	Rejected heat from industrial processes	70–100 °C	Heat exchanger	Heat exchanger	Not suitable
	Rejected heat from refrigeration and compressed air systems, ventilation exhaust air	30–40 °C	Air-to-water HP	Air-to-water HP	Air-to-water HP
Data centres	Server room cooling, central cooling devices	25–35 °C	Air-to-water HP	Air-to-water HP	Air-to-water HP
Shopping malls	Rejected heat from refrigeration systems	30–50 °C	Air-to-water HP	Air-to-water HP	Air-to-water HP
Wastewater treatment	Post-treatment sewage water	8–15 °C	Not suitable	Water-to-water HP	Water-to-water HP
Electric transformers	Transformer air cooling system	25–30 °C	Not suitable	Air-to-water HP	Air-to-water HP

2.1.1. Estimating National Waste Heat Potential

The general approach for waste heat potential quantification is derived from previous studies in the field. Table 2 shows the overall input data used to quantify the heat recovery potential. The derived input parameters are multiplied by a waste heat factor that differs among the considered heat sources and their temperatures. The estimations of waste heat factors are described further in this section.

Table 2. Waste heat potential determination on a national scale.

Waste Heat Source	Input Data	Waste Heat Recovery Factor	Temperature Levels		
			<30 °C	30–60 °C	>60 °C
			Ultra-Low DH System	Low-Temperature DH	Existing DH Network
Biomass boiler houses and CHP	PEC *	Share of PEC	n/a	25%	20%
Other boiler houses and CHP	PEC	Share of PEC	n/a	15%	10%
Industrial facilities					
Chemical industry	PEC	Share of PEC	n/a	7%	15%
Iron and steel	PEC	Share of PEC	n/a	18%	11%
Food, drink, and tobacco	PEC	Share of PEC	n/a	21%	6%
Non-ferrous metals	PEC	Share of PEC	n/a	9%	10%
Non-metallic minerals	PEC	Share of PEC	n/a	13%	11%
Paper and printing	PEC	Share of PEC	n/a	0%	13%
Wood and wood products	PEC	Share of PEC	n/a	20%	6%
Other waste heat sources					
Data centres	Total power consumption	Share from power consumption	44%	30%	n/a
Electric substations	Number of substations	Amount per substation	560 MWh/year	n/a	n/a
Retail stores	Retail store area	kWh/m^2	30	20	n/a
Wastewater treatment plants	Volume of wastewater	kWh/m^3 of wastewater	6.97	n/a	n/a

* PEC—Primary energy consumption.

The waste heat factor for the heat recovery from flue gases in boiler houses and CHP in this study assumes that 20% of heat could be recovered by integrating flue gas condensers in biomass-based facilities [19]. An additional 5% of heat could be recovered in the case of a low-temperature DH system using additional deep cooling of flue gases by integrating a heat pump. The heat recovery potential is lower for natural gas-fired energy plants due to lower latent heat content in flue gases. Therefore, the authors assume a waste heat recovery factor of 10 to 15%.

The industrial waste heat recovery factors are derived from previous research [16,45–47] that analysed industrial processes and their temperature levels. Some authors previously estimated the waste heat potential from the industrial sector in Latvia [48]. However, the potential was not divided into different temperature levels depending on the DH system requirements. Therefore, the primary energy consumption (PEC) in each industrial sector is multiplied by the estimated waste heat factor (see Table 2) to estimate the waste heat potential with low and high-temperature levels.

The waste heat potential in data centres depends on the total power consumption of the equipment—servers, networks, and power coordination equipment. Based on research by Luo [49], the power consumption of IT equipment accounts for 44% of the total power consumption of data centres. An alternative method [50] for calculating data centre equipment using the data centre's total electricity consumption is to use the power usage effectiveness factor, which indicates the ratio of total power consumption and consumption of equipment. If detailed technical information is available, electricity consumption can be calculated according to the methodology developed by Chung and Wang [51], using the number of different cells in the data centre, operating speed, and frequencies. However, there are very limited input data available on data centres in Latvia. In the preliminary assessment, the 20 largest data centres have been identified and their power consumption surveyed. The waste heat factor for heat recovery and integration into ultra-low temperature DH systems has been estimated to reach 44% of the total power consumption, but for the low-temperature DH system level, it is assumed that this potential would be lower at 30% due to the necessity to increase waste heat temperature.

Another ultra-low-temperature heat source is wastewater treatment plants. The most important parameters for using treated sewage water waste heat are temperature level and flow rate. These parameters determine the possible amount of heat Q_s that can be recovered according to (1).

$$Q_s = G \cdot c_p \cdot \rho (t_1 - t_2), \tag{1}$$

where G (m^3) is the annual amount of purified sewage, t_1 (°C) is the sewage temperature before heat recovery, and t_2 (°C) is the sewage temperature after heat recovery. C_p (kJ/(kg·K)) refers to the specific heat of the flow and ρ is the average density of the sewage water. In previous studies [52], it has been estimated that if the potential temperature drop for sewage water is around 5 °C, the annual waste heat recovery potential could be around 6.97 kWh/m^3 wastewater.

The heat recovery potential from retail stores is determined by combining the methodology used in the ReUseHeat project provided by Persson [53] and information from retail building energy-efficiency certificates regarding the cooling system energy consumption. Within the national scale assessment, only waste heat potential from the largest retail stores (floor area above 1000 m^2) has been analysed. The data on the total area were collected from large retail chain stores.

Previous research [54] shows that the waste heat potential from electric transformers can be obtained by knowing the voltage and the nominal power of the electric substation. By adjusting the results of Petrovic et al. [29], it has been assumed that a 330 kV transformer can produce 18,400 MWh per year and a 110 kV transformer can produce 560 MWh per year. The main parameters of electric substations in Latvia have been provided by the national transmission operator.

2.1.2. Comparison of Waste Heat Utilisation Strategies Using a Multi-Criteria Assessment

Waste heat potential utilisation strategies are compared using a multi-criteria assessment method by identifying the main impacting aspects when integrated into the DH systems with different temperature levels. Nine criteria were identified to assess the waste heat future role in existing, low-temperature, and ultra-low-temperature DH systems. Table 3 summarises the identified criteria, among which there are both qualitative and quantitative criteria. The section below describes the methodology for the determination of each of them.

First, the technical waste heat potential under different temperature levels is calculated using the quantification methodology described in Section 2.1.1. Within the assessment, detailed spatial analyses are included since the exact location of future ultra-low temperature DH systems is unknown. However, based on previous research, the spatial factor is attributed based on the mapping of existing DH systems and waste heat locations. In previous studies, authors have assumed that 86% of the high-temperature waste heat is in DH areas. For low-temperature DH systems, the waste heat potential spatial location and availability have been assumed to be slightly higher (90%), as the identified heat sources are mainly urban excess heat [48].

Table 3. Overview of identified criteria for comparison of different waste heat utilisation strategies.

Criterion	Unit	Criteria Type	Source	Desired Condition
Waste heat technical potential	GWh	Quantitative	Described in Section 2.1.1	Max
Necessary power input	kWh/MWh	Quantitative	[20,55]	Min
Heat supply share	Estimated % of national heat demand	Quantitative	[56]	Max
Optimal heat density for new connections	MWh/m	Quantitative	[57,58]	Min
Average heat losses of the network	% of heat production	Quantitative	[48]	Min
Exergy utilisation rate	n/a	Quantitative	[59]	Min
Necessary investment costs	n/a	Qualitative	[60]	Min
Impact on existing RES-based heat supply equipment	n/a	Qualitative	[61]	Min
CO_2 reduction potential	n/a	Qualitative	[62,63]	Max

Another important aspect of waste heat valorisation is the operation of HPs to ensure the necessary temperature levels to provide space heating and domestic hot water preparation in buildings. Therefore, the approximate level of HP efficiency is calculated. To find the average COP of the HP based on the DH supply and return levels, the following formula is used [55]

$$COP_{off} = COP_d + a(T_{source,i} - T_{source,i,d}) + b(T_{DH,s} - T_{DH,s,d}) + c(T_{DH,r} - T_{DH,\,r,d}), \quad (2)$$

where COP_{off} is the COP for off-design operation; COP_d is the COP for design conditions; $T_{source,i}$ is the heat source inlet temperature for off-design operation of heat source i (K); $T_{source,i,d}$ is the heat source inlet temperature for design operation of heat source i (K); $T_{DH,s}$ is the DH supply temperature for off-design conditions (K); $T_{DH,s,d}$ is the DH supply temperature for design conditions (K); $T_{DH,r}$ is the DH return temperature for off-design conditions (K); $T_{DH,r,d}$ is the DH return temperature for design conditions (K); and a, b, and c are coefficients based on linear regression [20].

The constants and coefficients in formula (2) depend on the temperature level of the DH systems where an HP is used and are given in Table 4 (see [20,55]).

Table 4. Parameters for off-design COP calculations.

Parameter	High-Temperature DH Network	Low-Temperature DH Network	Ultra-Low-Temperature DH Network
COP_d	2.91	3.75	3.75
$T_{source,i,d}$	7 °C	7 °C	7 °C
$T_{DH,s,d}$	90 °C	60 °C	20 °C
$T_{DH,r,d}$	60 °C	30 °C	10 °C
A	0.0286	0.0562	0.0562
B	−0.013	0.0290	0.0290
c	−0.013	0	0

According to the classical COP definition in thermodynamics (3), the amount of heat given to the network should decrease when COP is higher. The Lorenz efficiency factor

η_{Lorenz}, which is the ratio between actual HP COP and ideal COP, is estimated to be the same for high and low-temperature DH networks.

$$\text{COP} = \frac{Q_n}{Q_n - Q_s} \cdot \eta_{Lorenz} \quad (3)$$

From the estimated average COP values, the necessary power consumption for waste heat integration using the HP application is determined and included within the multi-criteria assessment.

Another criterion describes the overall heat supply share of each DH system type attributed to the existing situation and future potential. For the existing DH systems, the actual statistical data on connected buildings are used. The heat supply potential for low-temperature and ultra-low-temperature heat supply systems is assumed from analyses in the literature by considering the potential barriers to wide-scale implementation.

The main benefit of lower heat supply system implementation is attributed to lower DH network losses and the possibility of implementing DH in low-density areas. Therefore, two criteria based on analyses in the literature are included to represent these aspects. In addition, the exergy utilisation rate considers different temperature levels of heat supply temperatures of analysed DH systems as well as consumer requirements for necessary space heating and domestic hot water temperatures. The methodology for exergy utilisation rate calculations is described by Gong & Werner [59].

Finally, three qualitative criteria are added to the multi-criteria assessment due to their project-specific nature; therefore, the impact scale is used for evaluation. The necessary investment costs are scaled from 1 (low necessary investment costs for waste heat integration) to 3 (high necessary investment costs). The impact on already-implemented RES technologies is rated as 1—no impact on the operation of existing heat supply and 3—high impact on existing RES technologies. This criterion is included since there are many biomass-based DH systems with installed new equipment and recent investments that have not yet paid off. Finally, the last qualitative criterion is the CO_2 reduction potential from the waste heat utilisation, which is evaluated as high (3 points) for the existing DH systems, which are either fossil fuel-based or biomass-based with fossil fuel peak load boilers covering the part of heat demand. The potential is lower (1 point) for both low-temperature DH systems, which are assumed to be already RES-based.

Further, the multi-criteria assessment method is used to compare the analysed waste heat integration strategies. The TOPSIS decision-making method chooses the shortest distance from the ideal solution and the most significant distance from the perfect negative solution [64]. The criteria values are normalised to transform the assigned values into non-dimensional attributes, allowing comparisons across measures. Within this assessment, it is assumed that all criteria are equally significant. The positive ideal solution (4) and the negative ideal solution (5) are calculated using the normalised decision-making matrix.

$$d_a^+ = \sqrt{\sum_i \left(V_i^+ - V_{ai}\right)^2}, a = 1, \ldots, \text{m} \quad (4)$$

$$d_a^- = \sqrt{\sum_i \left(V_i^- - V_{ai}\right)^2}, a = 1, \ldots, \text{m} \quad (5)$$

where V_{ai} is the normalised criterion and V_i^+ and V_i^- are the ideal positive and negative weighted solutions for each criterion, respectively.

The last step within the TOPSIS method is the determination of the closeness to the perfect solution (6), which allows ranking waste heat valorisation strategies.

$$\text{C}_\text{a} = \frac{d_a^-}{d_a^+ + d_a^-} \quad (6)$$

2.2. Bottom-Up Approach for DH Operator Decision-Making

The waste heat potential and integration into the existing heat supply system have been validated for the small-scale urban area in Salaspils, which is considered one of the most innovative DH systems in the Baltic States [65]. The heat is supplied using a large-scale solar thermal field in the summer period and biomass boilers in the high heat demand period from September to April. In addition, natural gas boilers are used for peak demand coverage (see Figure 3). A thermal storage tank of 8000 m^3 is used to accumulate solar energy [66]. However, the capacity would not be suitable to store additional heat amount from waste heat sources. The heat supply temperature level of the analysed DH system varies from 90 °C in the heating season to 65 °C in the summer period; therefore, it can be considered a high-temperature DH system.

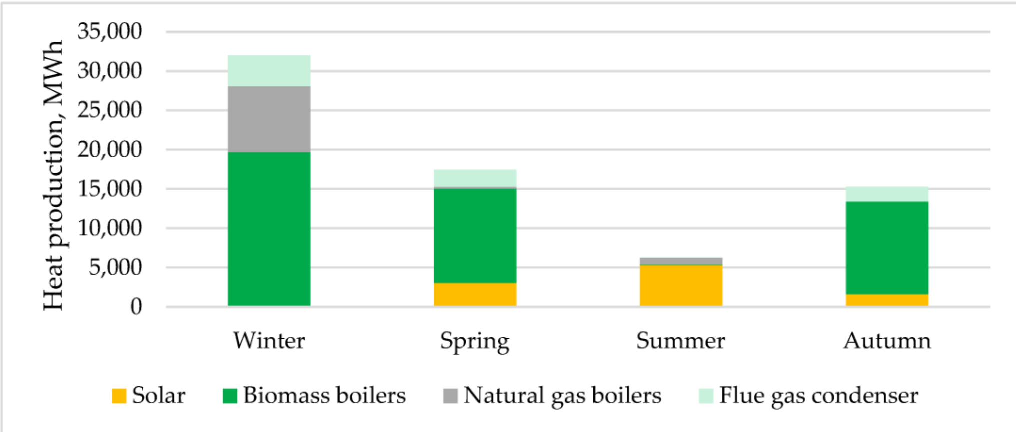

Figure 3. Distribution of heat production divided by fuel type for the analysed DH system in 2021.

Sources of excess heat in the city of Salaspils were initially selected according to their type of business, area, and location. Within the preliminary assessment, 25 different waste heat sources were identified within the urban area. The municipal buildings such as educational institutions, the city council building, the swimming pool, and others, were not considered in the further assessment due to the relatively small amount of heat recovery potential compared with other waste heat sources.

The next selection criterion for waste heat assessment was the location for which the spatial analyses were used (see Figure 4). When the selected enterprises were compiled and the approximate distance from the heating networks was determined, the estimation of waste heat potential and data collection took place. A survey regarding the main technical parameters and energy consumption was used to determine the necessary data for waste heat assessment. The data collection was carried out by surveying companies via e-mail and phone and on-site visits. In addition, the information was gathered using publicly available permits for polluting activities.

After the preliminary assessment and spatial analyses, 12 different waste heat sources were selected for further evaluation. The potential waste heat sources include 5 retail stores, 5 industrial objects (metal and wood processing enterprises), one wastewater treatment plant, and one electric transformer. The main characteristics and input data used for the assessment are summarised in Table 5.

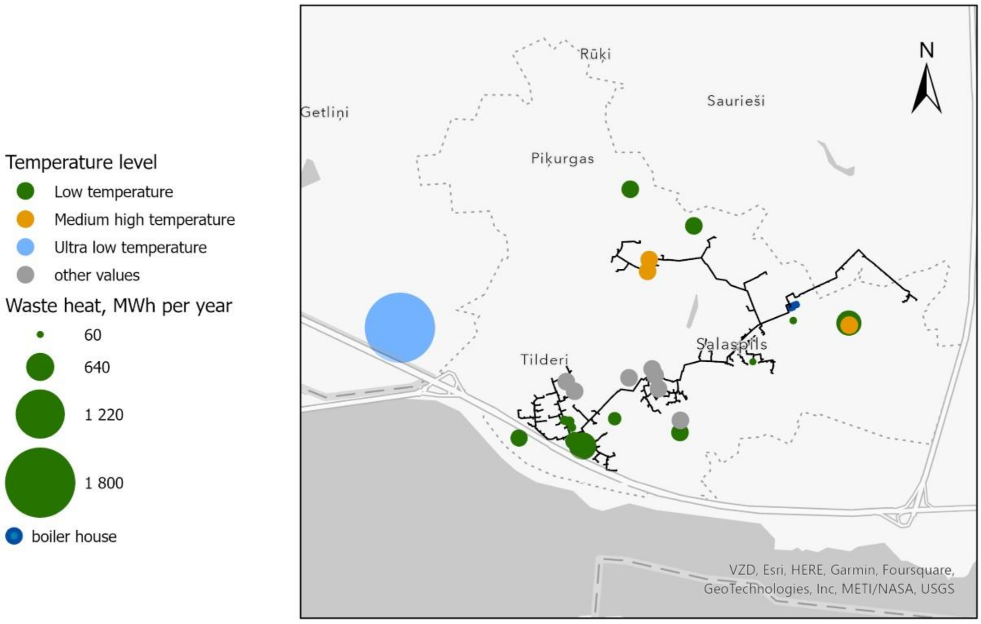

Figure 4. Preliminary assessment of available waste heat sources in Salaspils.

Table 5. Review on identified retail stores as waste heat sources.

Name	Type	Building Area or Other Describing Parameters	Heat Source	Power Consumption, MWh/y	Heat Consumption, MWh/y
RS 1	Retail store	918 m^2	HP	603	0
RS 2	Retail store	524 m^2	DH	191	78.6
RS 3	Retail store	3639 m^2	Gas boiler, solar collectors	1019	435
RS 4	Retail store	2410 m^2	HP	n/d	n/d
RS 5	Retail store	3457 m^2	n/d	n/d	n/d
MP 1	Metal processing	7049 m^2	DH	1106	342
MP 2	Metal processing	4359 m^2	DH	n/d	n/d
MP 3	Metal processing	2370 m^2	Gas boiler	n/d	48
MP 4	Metal processing	1324 m^2	Gas boiler	n/d	624
WP	Wood processing	2366 m^2	Biomass boiler	n/d	1102
WWTP	Wastewater treatment plant	982 thousand m^3/y	n/a	n/d	n/a
ET	Electric transformer	223 MVA/330 kV	n/a	n/d	n/a

Within the analysed area, there are four different metal processing enterprises. However, only one of the surveyed companies (see MP 1 in Table 5) was ready to share more detailed information on technological processes and data on energy consumption. The company has an approximate production capacity of 1200 t/year for metal products. The metal heating processes are carried out in five furnaces that are powered by electricity (total power consumption of 80 MWh per year). The mechanised painting line consists of a product painting preparation plant, a drying machine, and a painting chamber. The installed power of the painting line is 180 kW and, on average, the electricity consumption per month is 15 MWh. To ensure technological processes, two compressors with a capacity of 36 kW and 16 kW are installed at the enterprise. Total electricity consumption at the enterprise is 1106 MWh/year. Total heat consumption for space heating and hot water preparation is 343 MWh/year. Heat is obtained from the DH network.

The premises of the enterprise have high energy-efficiency improvement potential through building insulation. Therefore, some of the recovered heat flows could be used internally. Several options for waste heat recovery have been identified. Additional heat recovery from compressed air systems could be introduced. The excess heat could also be collected from the mechanised painting line and returned into production or utilised via the DH network.

Five retail stores were identified as potential waste heat sources in Salaspils city. The main characteristics of the identified retail stores are described in Table 5. The main input data for waste heat potential determination is the electricity consumption of the stores shown in Figure 5. In all stores, electricity is mainly consumed for indoor climate equipment, refrigeration and cooling systems and lighting. RS 2 has already implemented heat recovery from the regeneration system with a thermal capacity of 64 kW. The recovered heat is used to provide hot water in the store. Also, RS 3 is recovering thermal energy from cooling systems. In this store, solar collectors are also installed on the roof of the store for the preparation of hot water. The energy consumption data were available only for 3 retail stores (see Figure 5); therefore, the average values were used for the stores without data available.

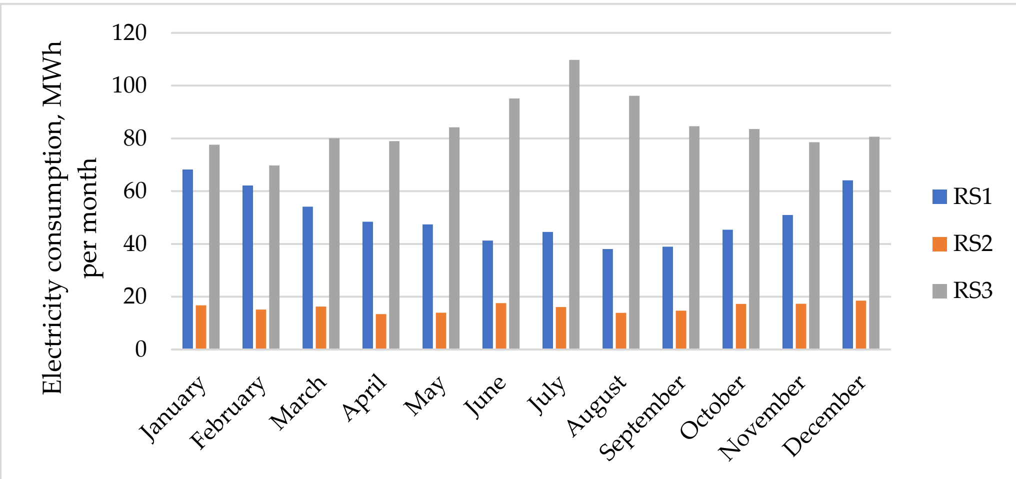

Figure 5. Distribution of total electricity consumption in analysed retail stores.

In addition to the waste heat sources described above, the 223 MVA electric transformer station for high-voltage direct current (330 kV) conversion to low-voltage altering current (110 kV) was identified as a potential waste heat source. The heat that is transferred from transformer oil to air is considered a source of waste heat since it is discharged into the environment at relatively high temperatures. The temperature of the oil and, therefore, the air depends on the ambient temperature and losses, which depend on the power load. According to Jarmen et al.'s case study, the 240 MVA/400 kV autotransformers could generate 1025 kW of waste heat at 60% load [67]. A similar amount of waste heat potential has been estimated for the Salaspils case study.

Additional waste heat flows could be recovered from the city wastewater treatment plant, which is located around 2 km from the DH heating network. Data on wastewater flow rates and monthly average temperatures were obtained from the wastewater treatment plant. Therefore, the total amount of waste heat from wastewater could reach 6392 MWh per year.

After quantification of waste heat potential, the authors further develop the decision-making model, which aims to compare the identified waste heat sources from different integration aspects. Table 6 shows the identified criteria for the decision-making model, which slightly differ from those used for the national scale assessment. For the analysed DH system, additional criteria include the heat load alignment coefficient, which considers the seasonal mismatch of recovered waste heat and heat demand. It is calculated as the ratio of the average surpluses and shortages of waste heat and the total integrated waste heat amount. For the fuel-saving calculation, the actual heat production rates of the analysed DH system are used and compared with the waste heat potential from each source (see Figure 3). The waste heat recovery distribution among analysed seasons is based on the obtained data or assumptions derived from the research of Sendwall et al. [68].

Table 6. Overview of identified criteria for comparison of different waste heat sources.

Criterion	Unit	Desired Condition
Waste heat technical potential	MWh per year	Max
Linear heat density	MWh/m	Max
Power consumption for waste heat integration	kWh/MWh	Min
Share in total heat production	%	Max
Load alignment coefficient	n/a	Max
Reduced solar energy utilisation	MWh	Min
Primary energy savings	MWh	Max
Specific investment cost	EUR/MWh	Min

More detailed assessments are included regarding the impact on the existing heat generation units. The reduced solar energy utilisation factor considers how the integration of waste heat would impact the share of solar thermal energy. Therefore, the priority would be attributed to the waste heat sources that are available during periods with lower solar intensity. In addition, the primary energy savings are calculated as the waste heat integration would allow avoiding the use of biomass and natural gas for heat production. Finally, the specific investments are included as criteria by analysing the investment costs for new network pipelines and heat recovery equipment based on the temperature level of waste heat sources [30].

Further, the criteria values are normalised and compared following the same multi-criteria assessment steps as described in Section 2.1.1.

3. Results

The section presents the results for both top-down and bottom-up waste heat analysis frameworks. The national scale waste heat potential and the valorisation in different types of heat supply systems are presented in Section 3.1. The results of the decision-making model, which are used to determine which identified waste heat sources would be most suitable for the analysed DH system, are presented in Section 3.2.

3.1. Waste Heat Valorisation Model

The first step of the research was to identify and quantify the total available waste heat potential at different temperature levels (see Figure 6). The theoretical high-temperature waste heat potential for Latvia could reach around 1834 GWh per year, but the determined low-temperature waste heat is 3408 GWh per year. For comparison, the total heat production rates in DH systems in 2020 in Latvia accounted for 7514 GWh. The total ultra-low temperature recovered heat amount could reach 732 GWh per year.

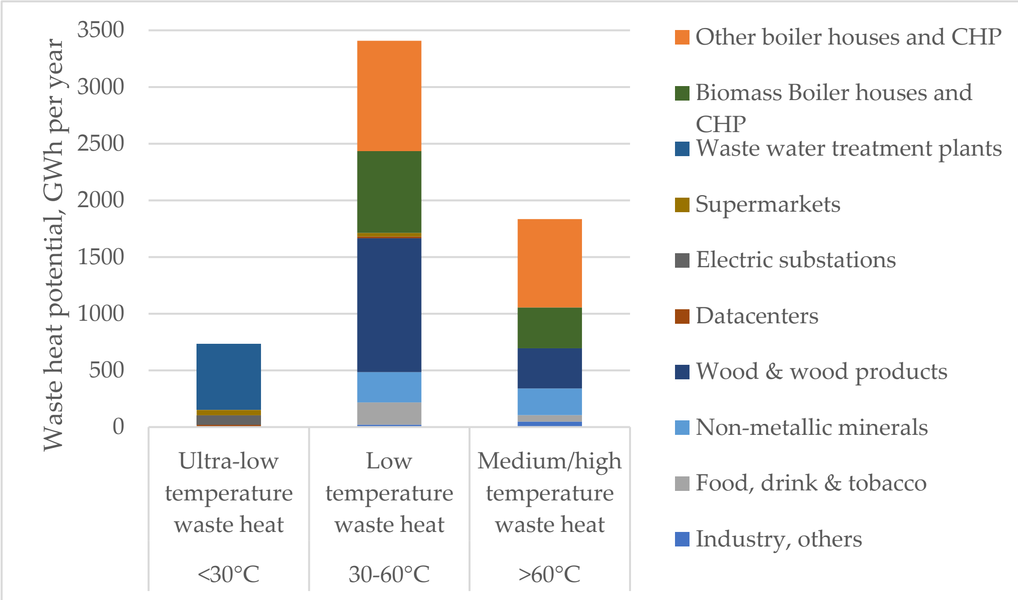

Figure 6. Total available waste heat potential assessment results for different temperature levels.

The highest identified heat recovery potential in the Latvia case study was identified for the energy sector facilities. With additional flue gas cooling technologies and direct heat recovery, it would be possible to recover around 1140 GWh of heat, but by integrating the HP and deep cooling of flue gases, this potential can be increased to 1695 GWh per year. A significant amount of low-temperature waste heat potential (1181 GWh) is identified in the wood industry, which is the main economic sector in Latvia. As can be seen in Figure 6, the determined waste heat amount from the data centres, retail stores, and electric transformers comprises only 20% of the identified ultra-low temperature waste heat potential, and the main part could be delivered from the threatened sewage water.

To further analyse the valorisation strategies for the identified waste heat potential, several criteria were calculated (see Table 7). The technical waste heat potential was determined by considering the approximate location of the waste heat objects from the previous research. The necessary specific power consumption is higher for ultra-low DH systems, which consider increasing the temperature at each consumer by implementing individual HP. In the case of existing DH systems and low-temperature DH systems, it is assumed that part of the waste heat could be integrated through direct heat exchange without HP application due to suitable temperature levels. From the statistical data, it is found that the existing DH systems provide heat supply to 70% of buildings. Due to the necessity to adjust the existing consumers to lower supply temperature levels, it is assumed that only around 40% of the necessary heat supply could be provided by low-temperature systems in the near future.

The ultra-low heat supply system concept requires more technical changes in the existing infrastructure. Therefore, it is assumed that such a system would be better developed as a new DH system for specific locations and would supply around 10% of necessary heat in the future. The lowest optimal heat density for connecting new consumers could be around 1 MWh/m in the case of the ultra-low heat supply concept, which would also result in the lowest heat losses in the distribution network, assumed to be around 5%.

Table 7. Obtained criteria value comparison among different waste heat valorisation strategies.

Criteria	Existing DH	Low-Temperature DH	Ultra-Low Temperature DH
Technical potential, GWh	1578	3068	659
Necessary power input, kWh/MWh	167	133	200
Heat supply share, %	70%	40%	10%
Optimal heat density for new connections, MWh/m	3.0	2.0	1.0
Average heat losses of the network [%]	15%	10%	5%
Exergy utilisation rate	5%	7%	15%
Necessary investment costs	1	2	3
Impact on existing RES-based heat supply equipment	3	2	1
CO_2 reduction potential	3	2	1

The calculated exergy utilisation rates based on supply, return, and consumed temperature levels range from 5% in high-temperature heat supply systems to 15% in the ultra-low DH system. This criterion shows the relation between the exergy demands of the consumer's final heat demands and the exergy supplied into the heat distribution network from the heat supply units. Future research could also include the estimation of exergy losses due to HP integration.

In addition, three qualitative criteria were used, for which the evaluation points are attributed based on the conclusions of previous research. The highest necessary investments for the integration of waste heat are assumed for the ultra-low temperature DH due to investments in individual HP. The integration of waste heat into existing DH systems could cause the highest impact due to the reduced operation time of already installed RES equipment. The highest CO_2 reduction potential is assumed for the existing DH systems due to the use of fossil fuels and biomass as main heat sources.

The determined criteria results were normalised and ranked according to the TOPSIS method. Figure 7 shows the ranking results for the waste heat integration, from which it can be concluded that the low-temperature DH system has the highest potential for waste heat valorisation due to high waste heat potential, relatively smaller investment costs, and increased transmission efficiency.

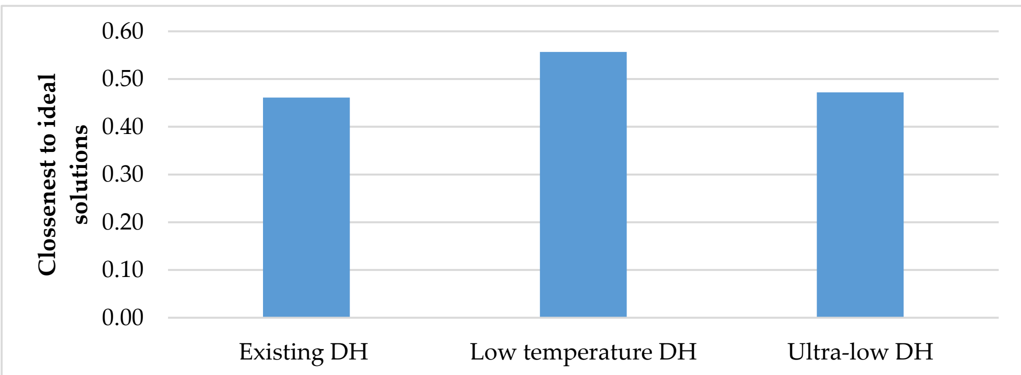

Figure 7. Waste heat valorisation potential comparison under different heat supply conditions.

3.2. Local-Scale Decision-Making Model

The authors estimated the heat recovery potential for the urban area of Salaspils for a further assessment of waste heat valorisation. Following the methodology of national scale waste heat potential assessments supplemented with more precise consumption data for some of the potential heat sources, it was determined that the waste heat potential in Salaspils could reach around 13.3 GWh per year. The heat sources with the highest waste heat potential are the electric transformer and sewage water. When analysing the waste heat potential among different seasons (see Figure 8), the highest share of waste heat potential occurs in the summer period, when it could cover around 72% of total DH heat demand, compared with only 7% in the winter period, when there are low outdoor temperatures and high heat demand.

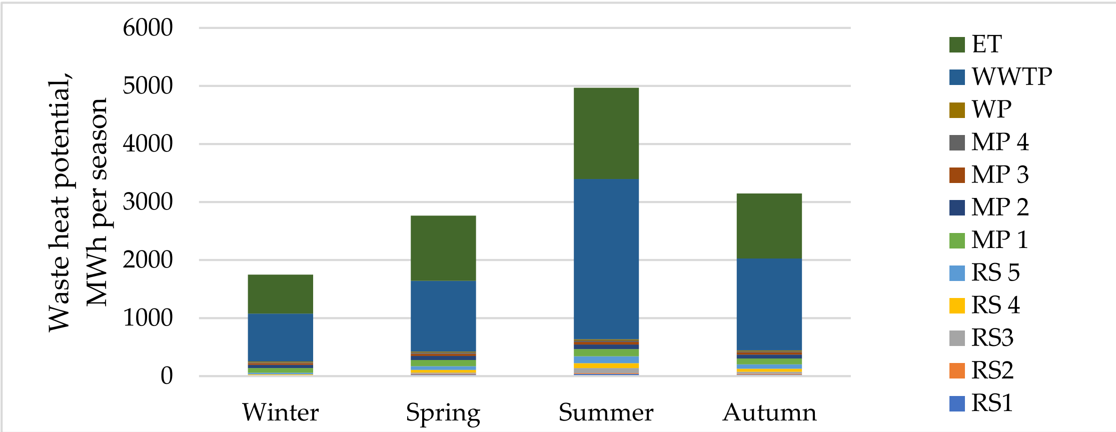

Figure 8. Waste heat potential distribution among seasons.

Table 8 shows the overall results for the other analysed criteria for the identified waste heat sources. The highest linear density value is obtained for the enterprises that are already connected to the DH system (MP 1, MP 2, RS 2) and for the electric transformer, which is located close to the heating network and has relatively high waste heat potential compared to other waste heat sources.

The lowest load mismatch coefficient is obtained for metal processing plant MP1, which has high production rates and power consumption in the winter period that could result in higher waste heat potential. The lowest specific power consumption is determined for industrial sites that have higher temperature levels for waste heat; therefore, lower necessary power for temperature lift is consumed by the HP. The highest share of total heat delivered to the DH network and highest primary energy savings are attributed to those waste heat sources that have the highest heat recovery potential—wastewater treatment plants, electric transformers, and metal processing sites (MP 1). Finally, the lowest specific investments are determined for the metal processing site, which is already connected to the DH network and therefore does not require additional investments for new pipelines.

The analysed waste heat sources are further ranked using the multi-criteria assessment method. Figure 9 shows that the highest rate is obtained for the integration of electric transformers due to relatively high identified waste heat potential, a small distance from the existing network, and enough waste heat occurring during the heating season. However, integration of this waste heat source would result in lower heat demand for the already operating solar thermal field. The decision-making model indicates that the waste heat flows could also be utilised and valorised from the wastewater treatment plant, one of the metal processing plants (MP 1), and the retail store (RS 2) that obtained a relatively higher score.

Table 8. Obtained criteria value comparison among different waste heat sources in Salaspils.

	Waste Heat Source											
Criterion	**RS 1**	**RS 2**	**RS 3**	**RS 4**	**RS 5**	**MP 1**	**MP 2**	**MP 3**	**MP 4**	**WP**	**WWTP**	**ET**
Waste heat potential, MWh/y	91	57	143	199	285	435	269	146	82	66	7035	4490
Linear heat density, MWh/m	1.82	5.73	2.85	0.74	1.06	86.94	13.44	0.58	0.16	0.26	3.52	14.97
Share from total heat production, %	0.1%	0.1%	0.2%	0.3%	0.4%	0.6%	0.4%	0.2%	0.1%	0.0%	9.9%	6.3%
Load mismatch coefficient, %	23%	10%	28%	20%	20%	25%	25%	25%	25%	25%	19%	15%
Power consumption, kWh/MWh	222	222	222	222	222	200	200	200	200	200	333	213
Primary energy savings, MWh	46	39	49	102	146	262	170	92	52	42	3247	2604
Reduced solar energy share, %	1%	0%	2%	2%	2%	2%	1%	1%	1%	0%	52%	29%
Specific investment cost, EUR/MWh	276	163	216	518	395	103	122	613	1937	1234	252	111

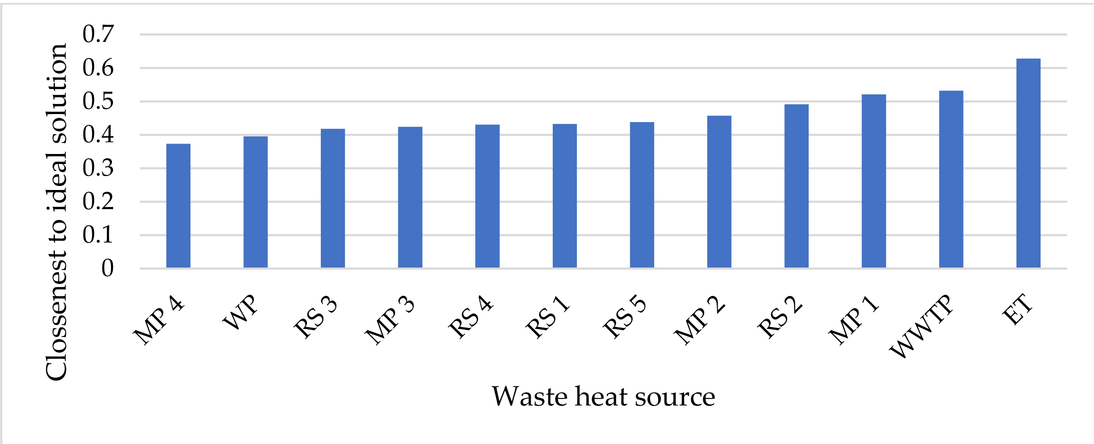

Figure 9. Decision-making results for ranking identified waste heat sources.

4. Conclusions and Discussion

This study analyses various waste heat integration and valorisation strategies in future heat supply systems by comparing the waste heat potential for existing high-temperature DH and future low and ultra-low heat supply systems.

The methodology is developed for assessing waste heat potential under different waste heat valorisation strategies by merging top-down and bottom-up approaches. The theoretical high-temperature waste heat potential for Latvia could reach around 1834 GWh per year and cover around 24% of the existing DH supply. The determined low-temperature waste heat reached 3408 GWh per year. The highest waste heat potential in Latvia could be recovered from the existing energy facilities—biomass-based CHP and boiler houses—by implementing flue gas condensers and the deep cooling of flue gases with HPs. The energy facilities, together with waste heat from the wood processing industry, would serve the highest share of the low-temperature waste heat potential. The determined waste heat amount from the data centres, retail stores, and electric transformers comprises only 20% of the identified ultra-low temperature waste heat potential. However, high uncertainty remains about the future role of ultra-low heat supply systems in countries with well-developed DH infrastructure, such as Latvia.

The local DH analyses show that the most beneficial waste heat sources are the electric transformer and wastewater treatment plant, which also have the highest waste heat potential. However, within the DH system, the utilisation of waste heat would impact the already operating solar thermal system because the heat recovery could cover around 70% of heat demand in the summer period.

The local scale assessment identified several waste heat sources with relatively small waste heat potential (small industrial sites and retail stores), which does not show the feasibility of being recovered under the existing heat supply conditions. However, such small-scale sources could be beneficial for low-temperature DH areas where there are no other already implemented RES heat generation technologies.

However, it is crucial to acknowledge certain limitations inherent to this study. One prominent limitation is the variation in technical parameters of DH systems across different countries. Different countries have distinct energy pricing structures and unique DH system configurations, which can significantly impact the feasibility and economic viability of waste heat integration and valorisation. Therefore, the insights and conclusions drawn from this study are specific to the context of Latvia and may not directly apply to other regions with distinct energy landscapes and DH infrastructures.

This study has highlighted the dynamic landscape of waste heat integration and valorisation in future heat supply systems, emphasising the importance of context-specific approaches. While substantial potential exists, realising it requires careful consideration of existing infrastructure, local conditions, and the evolving role of alternative heat supply systems. Future research should continue to explore these nuances and refine strategies for sustainable waste heat utilisation and integration of heat pumps.

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Article

Approaches to Sustainable Energy Management in Ensuring Safety of Power Equipment Operation

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Abstract: The study considers ways to ensure the quality of the functioning of power equipment as one of the directions for ensuring the safety of energy complexes in the period of "green transformation". Based on the analysis, it is established that for an effective "green" transformation, it is necessary to ensure the energy safety of equipment operation, which is possible by developing effective science-based approaches to technical diagnostics of the state of power systems and individual equipment. The main objective of the study is to develop a Safety Management Model for Life Term Operation of power equipment, which takes into account changes in its condition at different stages of operation and allows for the prediction of further safe operation. The paper proposes an approach to researching the technical condition of power equipment, taking into account the deformations that occur during operation. The results of the calculation of stress intensity coefficients for longitudinal and transverse-postulated cracks in different modes are presented. Based on the calculated and experimentally obtained values, an approach to predicting the operating life of power equipment with regard to changes in technical characteristics is proposed. The results of the calculations showed that by changing the allowable load on the material of the energy equipment to 35 kgf/mm^2, the estimated operational lifespan could be extended until 2035, ensuring all necessary safety conditions. It has been proven that with effective management and continuous safety diagnostics, nuclear power plants have the potential to operate beyond their standard design life of up to 30–40 years. This approach allows for the quality and safe operation of power equipment in the context of the transition to sustainable energy.

Keywords: sustainable energy management; safety; green energy; power equipment; long-term operation

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1. Introduction

Managing the security of energy facilities is an important strategic task for the development of sustainable energy. To ensure the sustainability of energy processes, it is necessary to develop a set of measures and actions that promote the development of energy and technologies while ensuring safety. To achieve a secure shift towards a "green" trajectory, it is essential to create a well-defined implementation plan that considers the resource requirements of the population while accounting for economic, environmental, and social implications. Among the critical resource factors influencing the quality of life, energy needs hold significant importance, and nuclear energy plays a crucial role in meeting these demands. In fact, in 2022, the European Commission recognized nuclear energy as green energy, acknowledging its contribution to the green transformation and the journey towards climate neutrality. However, ensuring energy safety and the secure operation of nuclear power plants and their equipment remains an essential prerequisite.

Ensuring the safe operation of energy facilities, both during their design and beyond their design life, is a crucial socio-economic and environmental undertaking, not only for Ukraine but also for the global energy industry. The significance of nuclear power plant safety during long-term operation (LTO) has escalated due to the growing number of licensees prioritizing assessments for the continued operation of these plants beyond their originally intended design timeframe. By the end of 2014, there were 438 operational nuclear power plants globally, with 225 of them having been in service for more than 30 years. A total of 68.27% of the reactors in the EU have been operational for over 30 years, and 30.8% of them are more than 40 years old, signifying that they have been granted an extended operational life beyond their initial design period, placing them in the category of LTO. As these plants approach the end of their operating licenses, they undergo a comprehensive safety review and ageing assessment of crucial structures, systems, and components. This evaluation is essential to either validate or renew their license to continue operating beyond the originally intended service period [1–6]. With some power units in Ukraine reaching or nearing the end of their design life, a significant objective is to extend their lifespan as part of the planned shift towards green energy, while prioritizing safety and dependability. Additionally, nuclear power remains a vital component of many countries' energy systems, enabling support for the energy sector during the transition to alternative energy sources. Absolutely, achieving safe and sustainable operation of energy complexes, as well as individual elements within them, heavily relies on effective approaches to quality assurance and safety management. These measures are essential for ensuring the reliability, longevity, and overall success of the energy sector's transition to greener and more sustainable practices.

Thus, today we have some contradictions, namely, for a safe "green" transition and further ensuring the stability of the energy sector, it is necessary to use nuclear energy, which in turn is now considered a "green" energy resource. At the same time, a significant number of nuclear power plants in the world have exhausted or approached their service life, which requires the development of a strategy for a smooth and safe transition to beyond design life and the definition of safety management mechanisms based on comprehensive technical diagnostics for continued operation.

This study aims to present an approach to ensuring energy management for the safety of power equipment operations. In this regard, the paper will analyze the latest research in the field of safety and effective management approaches based on selected articles and studies, which will help researchers and professionals in this field, and propose an energy management model taking into account the technical condition of power equipment. Thus, Section 2 will consider the analysis of approaches to the management of the safe operation of power equipment, after which, Section 3 will consider the management of energy security in the operation of power equipment, and thus, we will end with Section 4 concerning the results and discussions, and finally, with Section 5 referring to the conclusions.

2. Analysis of Approaches to the Management of the Safe Operation of Power Equipment

Green energy plays a crucial role in providing a sustainable source of non-carbon electricity. Safe and reliable operation of the power plant relies on advanced technologies and continuous improvement in management practices. However, owner/operating organizations of power plants are encountering significant challenges to their financial sustainability, especially in competitive electricity markets and with a decreasing or stagnant energy demand. To address these challenges and meet the climate change goals outlined in the Paris

Agreement, these organizations are re-evaluating their business models, adopting more robust and resilient approaches, and striving to maintain operational excellence. In recent decades, the energy sector has shown enhanced performance, thanks to the development of effective management models and processes within the green industry [6].

The safety of power plants depends on the reliability of their equipment, which includes structures, systems, and components. Achieving a high level of equipment reliability requires correct tasking, timely actions, and sufficient resources, which are managed through well-designed processes and programs. In the short term, a key method of ensuring equipment reliability is to predict and identify potential problems before they lead to unexpected equipment failure. Innovations using advanced technologies can complement these efforts by enabling more intensive equipment monitoring, longer trending intervals, and the use of sophisticated analytical algorithms to correlate system parameters and establish criteria for detecting potentially abnormal equipment behavior.

Enhancing the safety of power plant equipment involves advancements in monitoring methods and systems. From the perspective of nuclear reactor safety, research and accident risk assessments demonstrate that adverse events occur at a low rate compared to the overall estimated risk to human life in general. To reduce risks and elevate the safety level of power plant equipment, continuous efforts are required to enhance safety systems, safety management, and human resources [7,8].

Thus, nuclear energy plays a vital role in promoting sustainable economic development and maintaining its reputation as a "green" energy necessitates the active involvement of all stakeholders in ensuring operational safety. As indicated in references [7–12], the shift towards a circular, "green" economy is a gradual process, and the energy sector necessitates support and diligent attention to safety at every level and stage of power facility equipment operation.

Numerous studies in the review present equipment reliability models that explicitly incorporate not only baseline reliability but also the impact of aging, maintenance, and testing activities [13–16].

Ukrainian researchers have extensively investigated the safety aspects of power equipment operation during both its design and extended operational periods, given Ukraine's robust and advanced nuclear power system. Some research [17–19] has addressed the safety concerns related to various aspects of nuclear power plant components and equipment, offering diverse methods and approaches for technical diagnostics and enhancing regulatory support for operational safety. In [20], the authors proposed equipment standardization to distinguish methods and models for evaluating the technical condition of pipeline systems subjected to different types of loads and coolant mediums. Furthermore, papers emphasized the importance of conducting a comprehensive assessment of power equipment, considering its operational characteristics, to predict changes in technical condition and service life beyond the design period.

Ensuring the safe operation of power plant equipment requires a comprehensive approach to assess its quality and technical condition. For instance, for pipelines, researchers have proposed a comprehensive technical diagnosis of energy equipment, which considers structural features, defects, and stress–strain state after a specific period of operation [13,20–22]. The studies employ research methods like mathematical modeling, comparison of calculated and experimental results, identifying boundary parameters of the technical condition, predicting service life, and monitoring and controlling the mechanical properties of energy equipment during operation using non-destructive testing methods. They also involve determining the residual resource of metal structures and equipment, considering external factors. The suggested methods and algorithms of technical diagnostics can serve as the foundation for assessing the overall condition of energy equipment. The authors propose an actual analysis of the state of power equipment and the main disadvantage of these methods in comparison with the proposed one is the lack of possibility to make a comprehensive prognostic assessment taking into account possible operational changes.

Developing an effective mechanism to study the operational quality and assess the technical condition of energy equipment beyond its design service life requires the consideration of factors influencing both safety and economic indicators for future operations. Some research [23–26] explored approaches to optimizing the correlation between safety and economic indicators and criteria in this context.

Studies [27–31] have examined the challenges related to ensuring the safe operation of power plants from various perspectives. In these studies, the authors proposed cutting-edge information and measurement systems, smart technologies, and smart NPP concepts, along with innovative approaches to control system design and reliability assessment. Notably, these authors emphasize the importance of learning from past negative experiences of NPP operation, like the Chernobyl accident and Fukushima, underscoring the need for a robust system to ensure the safe operation of energy facilities.

However, new technologies also bring new risks to the energy industry. Thus, studies [32–34] propose Integrated Management of Safety and Security (IMSS) as a necessary means of preventing and preparing for accidents. It considers the risks posed by the development of digitalization and automation in high-risk industries and the resulting growing convergence of risks related to process safety, physical safety, and cyber security, which can lead to serious accidents. The authors of [35] propose an automatic generation control (AGC) for nuclear power plants (NPPs) to ensure the safety of NPP operation. The study is based on the hypothesis that with the development of the energy supply structure towards clean energy, NPPs will be a stabilizer of the power system and an effective advanced AGC strategy is needed, taking into account nuclear safety, relay protection of power units, automation of grid management, the power system stabilizer (PSS), and the speed control system.

Management of safety through the development of various models and approaches for risk assessment is examined in works [36–38]. Indeed, for this purpose, authors propose the use of Probabilistic Safety Analysis (PSA) technology, which has emerged as the predominant method worldwide, providing essential support for daily risk management and safety decision-making in nuclear power plants. Absolutely, PSA technology can be utilized to develop an aging PSA model for power plants during the license extension period. This model helps assess the effects of system, structure, and component (SSC) aging on the overall safety of nuclear power plants and verifies whether they still adhere to the original design standards [39–41]. By doing so, the extended operation can be ensured to meet the necessary safety requirements. To extend the operation license of a nuclear power plant, it is essential to consider nuclear safety during the extended service life. The goal is to ensure that the safety level of the power unit during the extended service life is at least as high as that of the original design life. Indeed, while PSA technology and other approaches have advanced the evaluation of safety and operational aspects of power equipment, there remain several unresolved issues related to conducting technical diagnostics and ensuring the overall quality and safety of power equipment functioning. These challenges require further research and development to effectively address and enhance the performance and safety of power equipment in various industries.

3. Energy Safety Management of the Power Equipment Operation

The primary document that defines the safe operation of a power unit is the technological regulation for safe operation. It establishes the limits and conditions for the safe operation of the power unit, as well as the requirements and fundamental practices for its safe operation. The regulation also outlines the general procedures for performing safety-related operations at the nuclear power plant.

As an example of technical diagnostics, pipeline systems for various purposes can serve as a crucial element of power equipment. The assessment of their technical condition is of utmost importance for ensuring the safe and efficient operation of the energy facility.

This study is limited to power unit equipment and its components that transport coolant at different stages of operation. The proposed approach can be used in the design, operation within the design life and, most importantly, in ensuring safe operation beyond the design life. This paper does not address the issues of technical diagnostics of the reactor and its equipment.

3.1. Analysis of Factors Affecting the Operational Safety of Power Equipment

The assessment of the technical condition and remaining lifespan of pipelines is carried out as part of control, assessment, prediction, and management of the resource characteristics of the nuclear power plant's components. This process includes evaluating and predicting the remaining resources of various elements of the nuclear power plant, which ultimately supports the extension of the plant's operational period.

Correct assessment of the technical condition and safety evaluations of pipeline systems involves a crucial examination of the mechanical properties of pipe metal, particularly its changes during long-term operation compared to normative data. The degradation of mechanical properties can significantly impact the technical condition and safe operation of pipelines, leading to accelerated wear and activating other factors that negatively affect the operational safety of energy equipment. Some of these factors include:

1. Increased vulnerability to fatigue and stress-induced failures.
2. Reduced material strength and structural integrity, leading to potential leaks or ruptures.
3. Elevated susceptibility to corrosion and erosion, which can compromise the integrity of the pipeline.
4. Diminished resistance to external forces, such as seismic events or environmental impacts.
5. Reduced ability to withstand operational stresses and dynamic loads, increasing the likelihood of unforeseen failures.
6. Potential impact on the efficiency and performance of the overall energy system, affecting its reliability and safety.

Therefore, a thorough understanding of the mechanical properties of pipeline metal over time is crucial for ensuring the safe and reliable operation of energy equipment. This knowledge aids in making informed decisions regarding maintenance, repair, and the extension of the equipment's service life, all contributing to the overall safety of the energy facility.

The primary design loads for pipeline systems include internal or external pressure, product mass and additional loads such as attached equipment, pipe insulation, etc. Other significant loads include reactions from supports and attached pipelines, temperature effects, and vibration-induced loads. There are no standardized methods prescribed for determining design loads, internal forces, displacements, stresses, and deformations of the analyzed elements. The chosen method should account for all design loads in all relevant scenarios and enable the determination of all necessary stress categories.

3.2. Determination of the Stress–Strain State of Equipment Metal

The main challenge in ensuring the safety and longevity of nuclear power plant equipment remains the issues of dynamics and strength. To achieve the primary goal of assessing the remaining service life and extending the operation of pipeline systems in power facilities under dynamic influences, it is crucial to evaluate the resistance to brittle fracture upon crack initiation on the metal surface.

The prediction of the remaining service life is based on a method for determining the stress–strain state of the metal, considering deformations resulting from various loads. The methodology involves assessing the technical condition of the selected equipment based on critical parameters and estimating the remaining service life through measurements and/or determination of the metal's limit state parameters, accounting for any defects that have arisen or by modeling possible changes.

3.2.1. Determination of the Allowable Stress Intensity

For research purposes, the main circulation pipeline of the South Ukrainian Nuclear Power Plant with a water-cooled water-moderated power reactor WWER-1000 was chosen as an example. The main circulation pipeline is a critical component of the overall energy block system, subject to various types of loads.

The main characteristics of materials used in calculations are the critical stress intensity factor K_{SI}, critical temperature of brittleness T_C, and yield strength $R^T_{p0.2}$.

The condition of crack non-propagation is also considered.

$$K_{SI} > K_{th} \tag{1}$$

where K_{th} is the threshold stress intensity factor, which is determined from the equation

$$K_{th} = \sigma_{th} Y \sqrt{\pi\alpha} \tag{2}$$

The strength condition is met when the stress intensity factor is less than the critical stress intensity factor.

$$K_{SI} < [K_{SI}]_i \tag{3}$$

where $[K_{SI}]_i$ is the allowable value of the stress intensity factor (MPa·m$^{1/2}$).

The index "*i*" indicates that the allowable values of stress intensity factors are selected differently depending on the operational conditions: *i* = 1—for normal operating conditions (NOC); *i* = 2—for hydraulic (pneumatic) testing (HT) and violation of normal operating conditions (VOC); *i* = 3—for emergency situations (ES).

To account for changes in material properties during operation, the determination of the allowable stress intensity factor is carried out considering the critical temperature of brittleness.

For pearlite steels, high-chromium steels, and their welded joints with a yield strength at 20 °C not exceeding 600 MPa (60 kgf/mm^2), the following generalized dependence of the stress intensity factor is used:

$$[K_{SI}]_1 = 13 + 18e^{0.02(T-T_c)}; \tag{4}$$

$$[K_{SI}]_2 = 17 + 24e^{0.018(T-T_c)}; \tag{5}$$

$$[K_{SI}]_3 = 26 + 36e^{0.02(T-T_c)}; \tag{6}$$

The critical temperature of material brittleness is determined using the formula

$$T_c = T_{c0} + \Delta T_T + \Delta T_N + \Delta T_F, \tag{7}$$

where T_{c0} is the critical temperature of material brittleness in the initial state; ΔT_T is the shift of the critical temperature of brittleness due to temperature aging; ΔT_N is the shift of the critical temperature of brittleness due to cyclic damage; and ΔT_F is the shift of the critical temperature of brittleness due to the influence of neutron irradiation.

3.2.2. Defect Modeling

The calculation of the resistance to brittle fracture for defect consideration is performed by modelling a postulated defect on each calculation segment. The defect is modelled as a longitudinal and transverse surface semi-elliptical crack with parameters *l/c* = 2/3, according to the requirements (Figure 1).

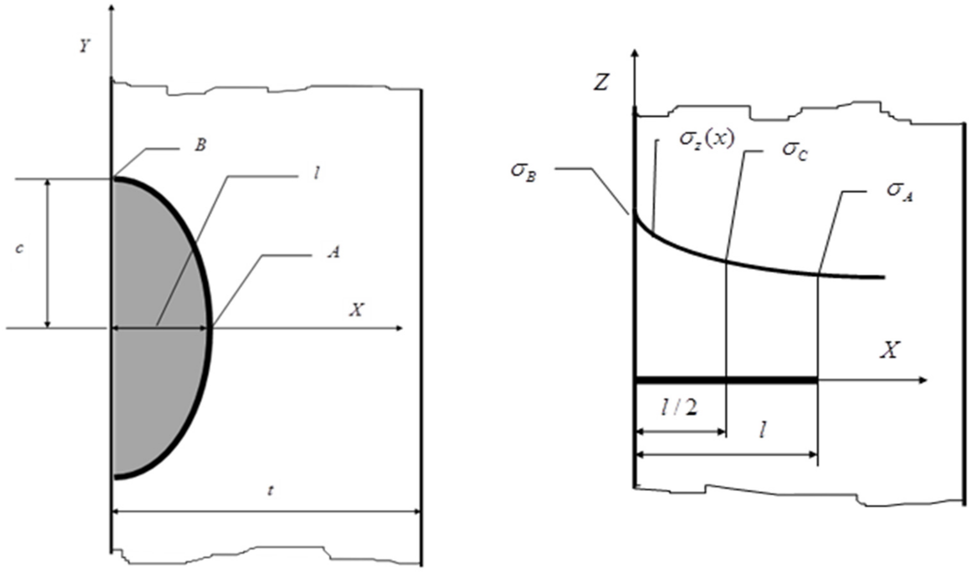


Figure 1. Surface semi-elliptical crack scheme.

The defect modelling was performed to predict the state of the metal, taking into account possible changes, in the event that actual tests did not reveal any changes or degradation effects in the metal of the power equipment. The actual condition was investigated using non-destructive testing methods in accordance with NPP safety standards and regulations.

The calculation of the stress intensity factor for the elliptical surface cracks (Figure 1) at points A and B is determined by the following formulas:

$$K_{SIA} = M_A N_A S_A \sqrt{\pi l/Q} \tag{8}$$

$$K_{SIB} = M_B N_B S_B \sqrt{\pi l/Q} \tag{9}$$

$$Q = 1 + 1.464\alpha^{1.65} \tag{10}$$

The crack parameter at point A is denoted as $N_A = \left[1 - \left(0.89 - 0.57\sqrt{\alpha}\right)^3 \tau^{1.5}\right]^{-3.25}$, $M_A = 1.12 - 0.08\alpha$; the crack parameter at point B is denoted as $N_B = \left(1 + 0.32\tau^2\right) N_A$, $M_B = (1.23 - 0.09\alpha)\sqrt{\alpha}$; l is the crack depth in millimeters; c is the crack width in millimeters; and $\alpha = l/c$ for $l \leq c$; $r = l/t$ for $l \leq 0.7t$.

In the general case of any stress distribution $\sigma_z = \sigma_z(x)$ in the wall of the element, as well as any shape of their application, the depth of the semi-elliptical surface crack is also divided into $2m$ segments. The number of points at which stresses are specified will be $K = 2m + 1$.

The coordinate of each point is determined by the expression

$$x_k = (k - 1/2m)l, \tag{11}$$

where $k = 1, 2, \ldots, 2m + 1$.

Stresses, which are specified in arbitrary form, are determined for each point x_k: $\sigma_k = \sigma_z\ (x = x_k)$.

The stress values for the points are determined using the following formulas:

$$\sigma_A = \sum_{1k=1}^{K} (B_{k,3} + \alpha B_{k,4} + \lambda B_{k,5})\sigma_k \tag{12}$$

$$\sigma_B = \sum_{k=1}^{K} B_{k,6}\sigma_k \tag{13}$$

$$\lambda = \tau(1 - 1.9 \cdot \alpha^{0.75} + 0.9 \cdot \alpha^{1.5}) \tag{14}$$

where $B_{k.3}$, $B_{k.4}$, $B_{k.5}$, $B_{k.6}$, for the k-th point ($k = 10$), the stress values are determined from Table 1 [42].

Table 1. Coefficients for calculating crack stress.

k	$B_{k.3}$	$B_{k.4}$	$B_{k.5}$	$B_{k.6}$
1	0.0189	−0.0085	0.0278	0.2700
2	0.0378	−0.0165	0.0548	0.1980
3	0.0370	−0.0160	0.0510	0.1120
4	0.0368	−0.0155	0.0472	0.0800
5	0.0367	−0.0149	0.0431	0.0620
6	0.0366	−0.0142	0.0390	0.0500
7	0.0367	−0.0134	0.0347	0.0410
8	0.0368	−0.0125	0.0303	0.0350
9	0.0371	−0.0115	0.0257	0.0290
10	0.0376	−0.0105	0.0207	0.0250

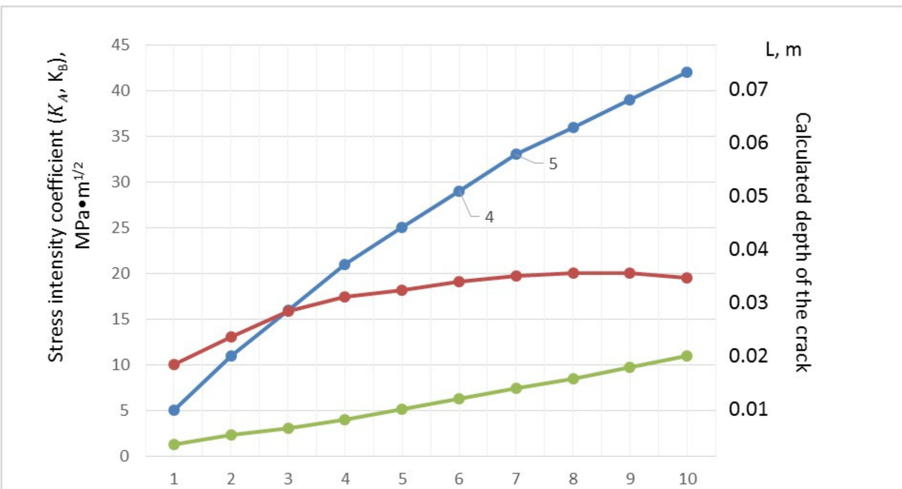
For a surface element that has curvature in the direction of the Z-axis, the coefficients of stress intensity are determined by the ratio (longitudinal crack; radius of curvature in the Z-axis direction, $R_z = R$):

$$K_{SIA}'^{1} = \frac{1 + 4\frac{l}{R_z}\left(1 - \sqrt{\alpha}\right)}{1 + 5\frac{l}{R_z}\left(1 - \sqrt{\alpha}\right)\left(1 + 2\tau^2\right)} K_{SIA};\ K_{SIB}' = K_{SIB} \tag{15}$$

3.2.3. The Results of Determining the Coefficients of Stress Intensity

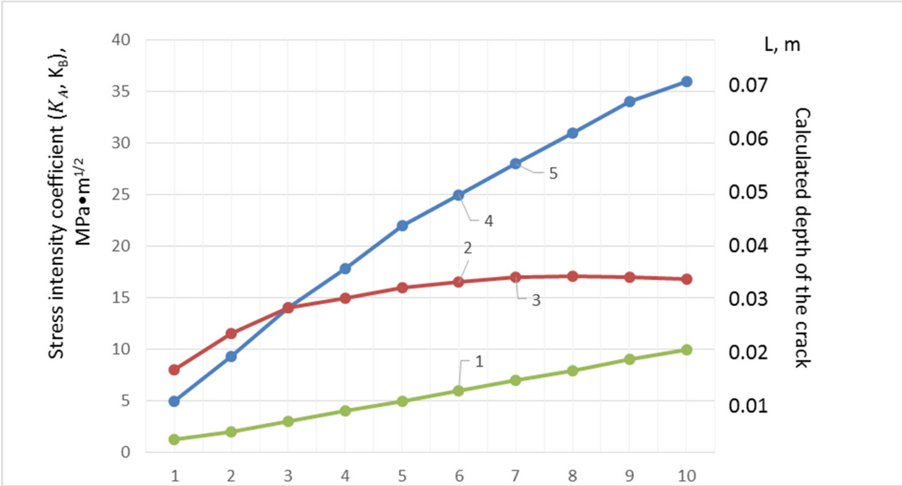
Using the proposed methodology, a calculation for the resistance to brittle fracture of the main circulation pipeline elements was performed at various sections.

The results of determining the stress intensity coefficients for the longitudinal Y-axis and transverse Z-axis of the conditional crack for normal operating conditions ("NOC"), violation of normal operating conditions ("NOC") and hydraulic (pneumatic) tests ("HT") are presented in the form of diagrams in Figure 2.



(**a**)

Figure 2. *Cont.*



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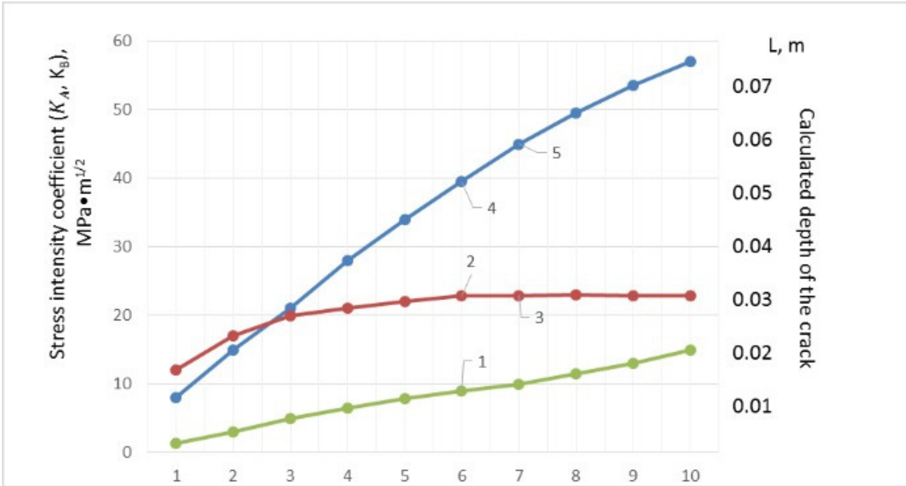
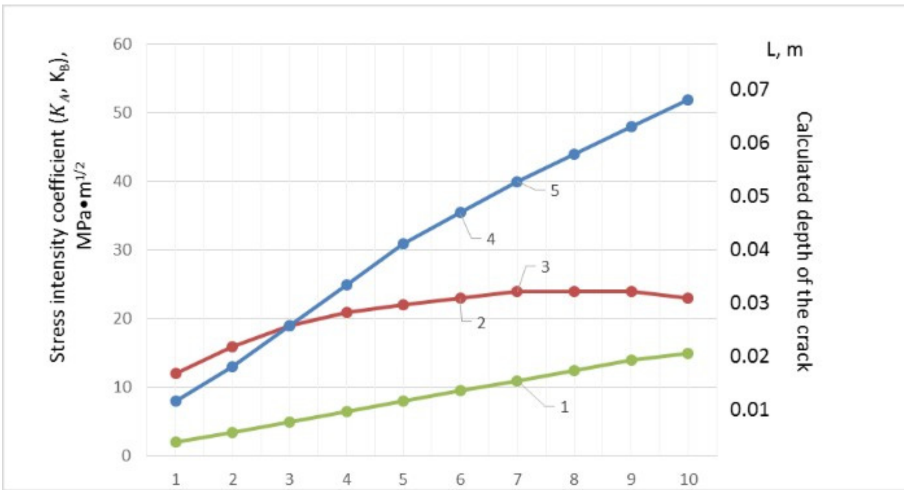


(**c**)



(**d**)

Figure 2. The diagram of stress intensity coefficients (K_{SI} for the Main Circulation Pipeline (MCP): (**a**) from the Reactor Casing to the Steam Generator for NOC; (**b**) from the Steam Generator to the Main Circulation Pump for NOC; (**c**) from the Reactor Casing to the Steam Generator for VOC; and (**d**) from the Steam Generator to the Main Circulation Pump for VOC. The numbers represent the following: 1 line represents the calculated depth of the crack, 2 and 3 from line represent the stress intensity coefficient (K_A) along the *Y*-axis at point *A*, and 4 and 5 from line represent the stress intensity coefficient (K_B) along the *Z*-axis at point B.

It is worth noting that the permissible stress intensity coefficient $[K_{SI}]_I < 65,000$ MPa·m$^{1/2}$.

As can be seen from the graphs (Figure 2), the values of stress intensity factors for the considered operating conditions are three orders of magnitude lower than the stress intensity factors that meet the operational requirements.

The defect modelling and subsequent calculation makes it possible to predict the safe operation of power equipment under certain cyclic loads, or to assess the actual condition of the metal of power equipment and develop recommendations for the service life. This makes it possible to develop a Long-Term Safety Management Model.

4. Results and Discussion

Based on the proposed method of considering the defect resulting from the operation of energy equipment and the corresponding cyclic loads, and using the determined stress intensity coefficients, the estimation of remaining service life and safety prediction for further operation is suggested. Some research [9,13] proposes mathematical models to analyze the changes in the mechanical properties of the metal pipeline, such as R_m^T, (ultimate tensile strength), $R_{p0.2}^T$ (yield strength), Z^T (total elongation), A^T (reduction of area), K_{SI} (stress intensity coefficients), and others, considering the regularities of metal property changes during operation. These models take into account the geometry of the defect and the accumulation of fatigue damage in equipment and pipelines under different operational loads.

Taking into account the data on the material of the main circulation pipeline, we will determine the values of permissible stresses for different calculation groups of stress categories.

For the metal of the main circulation pipeline (MCP), with the main material being 10GN2MFA steel:

$$[\sigma] = min\left\{R_m^T/n_m; R_{p0.2}^T/n_{0.2};\ R_{mt}^T/n_{mt}\right\} = min\{55.1/2.6;\ 41.79/1.5\} = 21.19\ \text{kgf/mm}^2$$

The normal operating conditions (NOC):

$$(\sigma)_1 = [\sigma],\ (\sigma)_1 = 21.19\ \text{kgf/mm}^2$$
$$(\sigma)_2 = 1.3[\sigma],\ (\sigma)_2 = 1.3 \times 21.19 = 27.55\ \text{kgf/mm}^2$$
$$(\sigma)_{RV} \le \left(2.5 - R_{p0.2}^T/R_m^T\right) R_{p0.2}^T = 72.8 \le 83.58\ \text{kgf/mm}^2$$

The hydraulic (pneumatic) testing (HT):

$$(\sigma)_1 = 1.35[\sigma],\ (\sigma)_1 = 1.35 \times 211.92 = 28.61\ \text{kgf/mm}^2$$
$$(\sigma)_2 = 1.7[\sigma],\ (\sigma)_2 = 1.7 \times 211.92 = 36.03\ \text{kgf/mm}^2$$

The calculated forecast of the change in the permissible load on the material of the main circulation pipeline (MCP) elements depending on the duration of operation is presented in Figure 3.

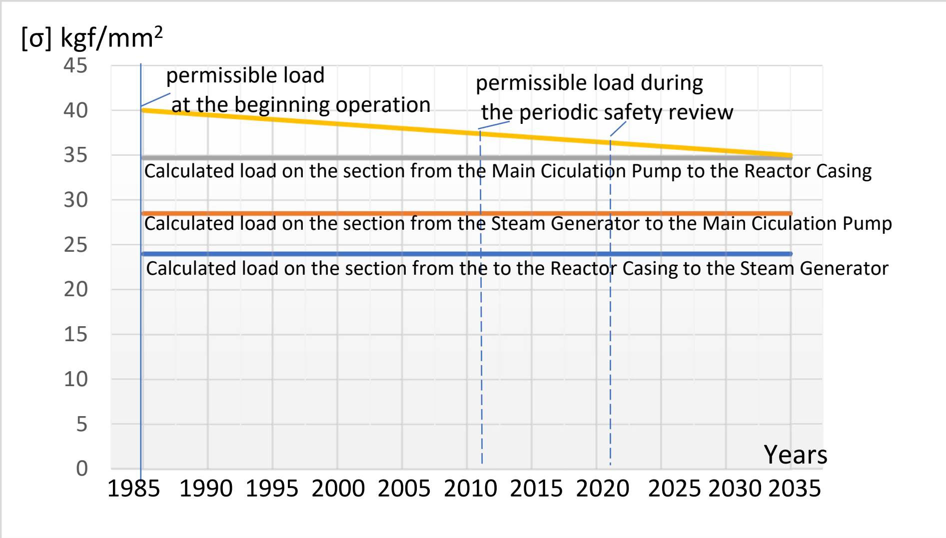


Figure 3. Calculated forecast of the change in permissible load on the material of the main circulation pipeline (MCP) elements.

Based on the results of technical diagnostics and calculated predictions of changes in the allowable loads, it can be concluded that the mechanical characteristics of all inspected elements are in agreement with the specified values and meet or exceed the regulatory requirements [43]. The refined forecast of metal changes in the energy equipment under different loads and considering potential defects indicates the possibility of safe operation until 2035. However, it is recommended to plan and carry out metal monitoring and assess changes in allowable loads during the periodic safety review (PSR-2024; PSR-2029) as part of the major overhaul in 2024 and 2029. To achieve this, a safety management scheme is proposed for determining the technical condition and critical parameters of the pipeline metal (energy equipment), aiming at Long-Term Operation (LTO) (Figure 4).

The Plant Safety Management Model is a system that defines the Life Term Operation of a nuclear power plant. LTO refers to the extension of the operational lifetime of a nuclear power plant beyond its original design life, while ensuring safety and reliability. The LTO process involves conducting comprehensive evaluations, technical diagnostics, and safety assessments to determine whether the plant's components, including the pipelines, can continue to operate safely and meet the required performance standards [44–47].

The Plant Safety Management Model includes various aspects, such as probabilistic safety analysis, aging management programs, material property assessments, and defect prediction models. By incorporating these elements, the model can predict the remaining service life of the equipment, including the pipelines, and estimate their future performance considering the effects of aging, degradation, and accumulated fatigue.

The results of the Plant Safety Management Model allow plant operators and regulatory authorities to make informed decisions about the continued safe operation of the nuclear power plant. It also helps in planning maintenance, repair, and replacement activities to ensure the plant's safe and efficient operation throughout its extended service life.

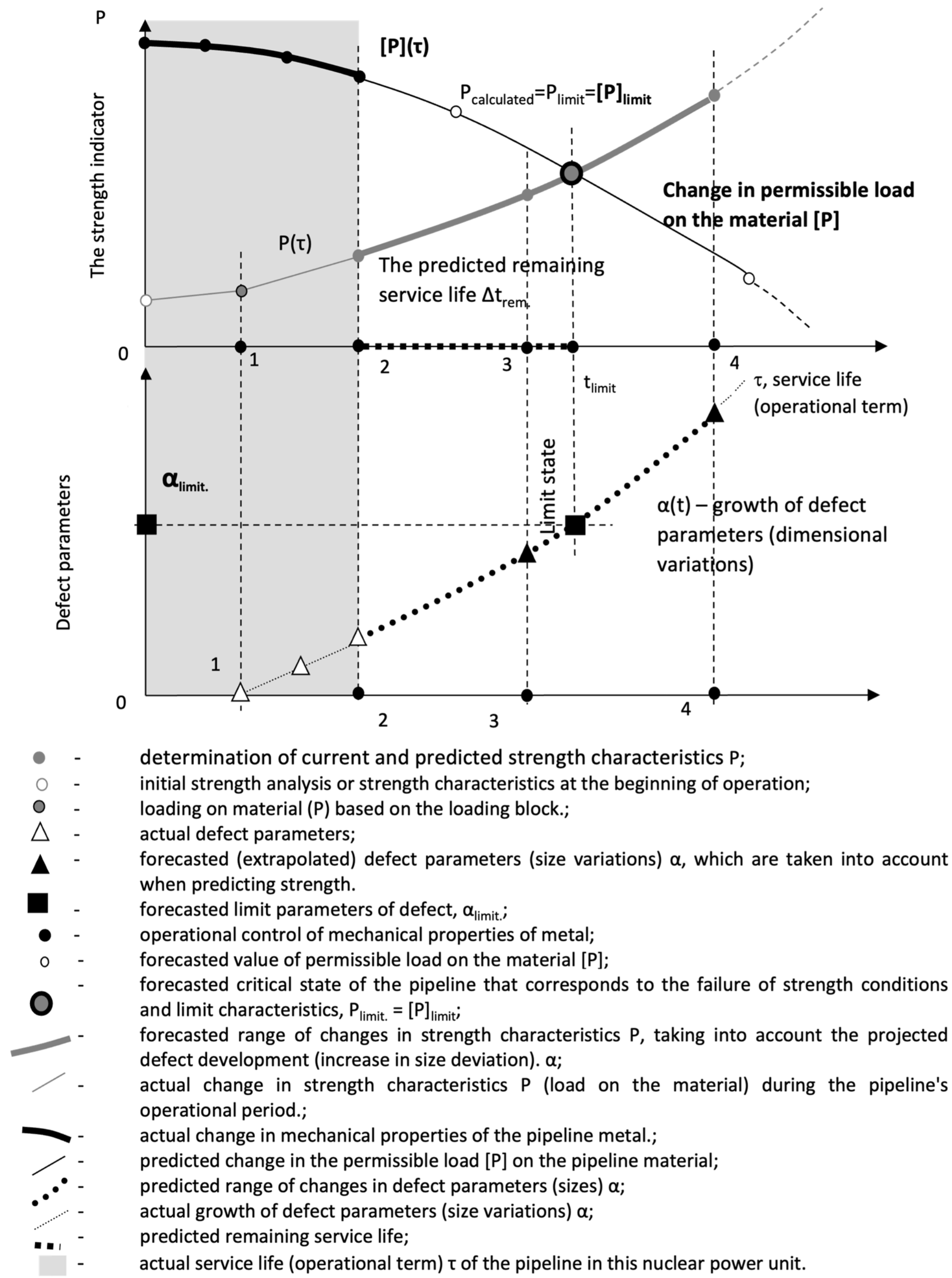


Figure 4. The Plant Safety Management Model for Life Term Operation Determination.

5. Conclusions

Aging of equipment and corresponding analysis of resource characteristics are important issues in Ukraine and worldwide. Research on the equipment's maximum service life is driven by a significant portion of equipment that has either reached its designed service life or exceeded it. Forecasting the equipment's service life, which is the subject of numerous studies, has shown that extending the service life of objects through partial replacement and equipment repair becomes economically and technically feasible. However, to justify extending the operational period, a thorough analysis of factors affecting the safety, functionality, and longevity of the energy equipment is necessary. Specifically, research on specific objects needs to be conducted regarding factors that determine the extent of deformation during prolonged operation. To determine the equipment's service life and justify the forecast for extending the operational period, data from regular monitoring of the mechanical properties of the base metal during the operational term are required.

Based on the assessment of the technical condition of the main circulation pipeline elements of the South Ukraine Nuclear Power Plant, the following findings regarding the main aging processes of the equipment and pipelines have been established:

- No changes in the shape or dimensions of the construction elements of the inspected components have been detected under the influence of operational loads.
- No metal defects or wall thinning have been observed from the beginning of the operation until the evaluation and reassessment of the service life of the mentioned equipment and pipelines.

A methodology for determining the stress intensity factors to account for possible defects due to operation was proposed. For this purpose, defects were modelled, and stress intensity factors were determined under different operating conditions. Resistance to brittle fracture is considered to be ensured (and the defect is considered stable) if condition (3) is met for the selected design defect in the form of a crack in the considered operating mode. The results of the brittle strength calculation were presented in the form of diagrams (Figure 2), which contain the values of the coefficient stress intensity factor for points *A* and *B* for the longitudinal and transverse cracks, as well as the value of the permissible stress intensity factor. As a result of the evaluation of the results of the performed calculation for resistance to brittle fracture, it can be concluded that the condition of brittle strength is met for all considered design zones and operating modes. The permissible stress intensity coefficient $[K_{SI}]_I < 65,000$ MPa·m$^{1/2}$ and as calculations show, the maximum values of stress intensity coefficient do not exceed 60 MPa·m$^{1/2}$.

The results of the calculations for the inspected elements formed the basis for predicting further safe operation. It was found that considering safety factors, the investigated equipment can be operated until 2035, and the values of mechanical characteristics and permissible loads do not exceed the normative limits ([σ] = 20 kgf/mm^2 with permissible values $[\sigma]_{limit}$ = 35 kgf/mm^2).

To refine the predicted values, it is recommended to conduct a technical diagnosis of the state of the power equipment in 2024 and 2029 using the proposed plant safety management model for life term operation determination. According to the proposed model, when conducting the periodic safety review, research should take into account changes in the stress–strain state of the equipment metal and strength calculations. In the case when a defect is not detected, modelling of changes and calculation with consideration of possible deformation is proposed.

Further research will be aimed at developing a regulatory methodology for technical diagnostics according to the proposed plant safety management model for life term operation determination, which will include a step-by-step algorithm for conducting research, a methodology for calculating the stress–strain state of power equipment and a methodology for predicting the service life and frequency of the periodic safety review.

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

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Advocacy Coalitions and Paths to Policy Change for Promoting Energy Efficiency in European Industry

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Abstract: This paper applied the advocacy coalition framework to explore and explain the political processes creating policies to enhance energy efficiency of European Union (EU) industry. The paper used legislation on energy audits and energy management systems as a proxy for EU policy on energy efficiency in industry. Based on qualitative text analysis of EU policy documents, including a proposal to recast the energy efficiency directive, amendments to the proposal suggested by Member States, the Council and the European Parliament, and reports from negotiations, the paper identified four advocacy coalitions with different core beliefs, spanning from those that want few companies to implement energy audits or energy management systems, and that recommendations from audits should not be mandatory to implement, to those that advocate that many companies implement energy audits and management systems and that it should be mandatory to implement measures recommended in audits. It was further found that policy change followed an external shock, deliberative negotiations, and policy-oriented learning. The identification of core beliefs and advocacy coalitions will help policymakers and other stakeholders become more aware of their own and others' values on energy efficiency and how these could be changed. As important was the differentiation of deep core beliefs, policy core beliefs and secondary beliefs. Which beliefs can be easily changed, which cannot?

Keywords: advocacy coalition framework; energy audits; energy efficiency; energy management systems; industry; process tracing; policy change; policy process

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1. Introduction

The Paris Agreement and, most recently, the Russian invasion of Ukraine put the spotlight of European Union (EU) energy and climate policy on energy efficiency measures to save energy, reduce greenhouse gas emissions, reduce import dependency from outside the Union, lower energy bills for households and companies, and alleviate energy poverty. Energy efficiency is seen as the 'first fuel' in the clean energy transition leading to multiple benefits [1,2]. Industry accounts for 26 per cent of the EU's final energy consumption [3], which makes it an important sector to develop policies for promoting energy efficiency.

In this study, the policy problem relates to the question of how to promote energy efficiency in industry. There is no single EU legislation for this, why EU legislation for promoting the use of energy audits and energy management systems in enterprises in EU member states (MSs) is used as a proxy for promoting energy efficiency in industry. The EU emissions trading scheme may also stimulate measures to improve energy efficiency as means to reduce greenhouse gas (GHG) emissions in companies covered by the ETS. Energy audits and energy management systems are seen as key instruments to improve energy efficiency in industry, both in large companies and in small and medium-sized enterprises (SMEs), e.g., [4–6]. Energy audits were regulated in the EU since the entry into force of the EU Energy Services Directive (ESD, 2006/32/EC) in 2006, requiring MSs to ensure the availability of efficient, high-quality energy audit schemes which are designed to identify potential energy efficiency improvement measures and which are carried out in an independent manner, to all final consumers, including smaller domestic, commercial, and small and medium-sized industrial customers. Article 3.l of the ESD defines energy audits as 'a systematic procedure to obtain adequate knowledge of the existing energy consumption profile of a building or group of buildings, an industrial or commercial operation or installation or a private or public service, identify and quantify cost-effective energy savings opportunities, and report the findings'. With the adoption of the EU Energy Efficiency Directive (EED, 2012/27/EU) in 2012, which repealed the ESD, provisions on energy audits were made mandatory for large companies. In its 2021 proposal for a recast of the EED, the European Commission (EC) [7] suggested that the provisions on mandatory energy auditing are changed. In addition, provisions on mandatory energy management systems were added. An energy management system is defined in the EED (Article 2.11) as 'a set of interrelated or interacting elements of a plan which sets an energy efficiency objective and a strategy to achieve that objective, including monitoring of actual energy consumption, actions taken to increase energy efficiency and measurement of progress'. In March 2023, after 21 months of negotiations and deliberations, the co-legislators of the EU, the Council of Ministers (Council) and the European Parliament (EP) reached an agreement that changed the provisions on energy audits from focusing on large companies to focusing on companies with high energy use. All enterprises, including SMEs that exceed 85 TJ of annual energy consumption, will have to implement an energy management system. Otherwise, companies will be subject to an energy audit if their annual consumption exceeds 10 TJ. This introduction of a new requirement for companies with highest energy use can be seen as a major policy change. In all, changing focus from large companies to companies with high energy use may pave the way for more cost-effective energy efficiency improvements [8]. The new provisions are deemed one of the three most important policies and measures of the EED in terms of contributions to energy savings and increased energy efficiency in the EU [9]. However, what made these policy changes happen?

Research on policy process on energy efficiency policy is scarce [10–13]. The aim of this paper is to analyze the political processes leading to the recent change of the EU legislation on energy efficiency in industry. What were the political conflicts and how were they resolved by policymakers? To answer this, the paper applied process-tracing [14] and the advocacy coalition framework (ACF) [15,16] in a qualitative case study, using empirical data from negotiations in the Council, the EP and trilogue negotiations between the Council, the EP, and the EC. The policy subsystem, the advocacy coalitions, and their core beliefs and coordinated behavior were analyzed, as were paths to a policy change. Based on the ACF and previous research on policy change regarding energy efficiency policy in the EU, three propositions are made:

1. There exist at least three advocacy coalitions, around the EP, the EC, and the Council, respectively;
2. The EP advocates stricter and more far-reaching core beliefs in favor of energy efficiency in industry than do the EC and the Council, while the Council advocates a weaker role of the public policy than the EC;
3. Policy change followed an external shock and a negotiated agreement.

Improved scientific knowledge of the policymaking processes and policy change and the role of different advocacy coalitions and their efforts to influence of EU policy can inform political science theory on the workings of the EU, including the workings of the Council and its relation to the EP and the EC, cf. [17]. It can also inform stakeholders to better shape their advocacy in EU policy-making. The paper gives scientists and stakeholders a glimpse into the private and somewhat 'confidential' means of communication with the other side, which usually characterize negotiations in the Council [18,19] and between the Council and the EP.

The remainder of the paper is outlined as follows. The next section summarizes the scientific and technical literature on energy efficiency in industry. Section 3 presents the theoretical framework, the research questions, the method used, and the demarcations made in the study. Section 4 presents and discusses the views of different actors and institutions on the Commission's proposal for a recast EED. Section 5 analyses the political creation of EU policy on energy efficiency in industry with the ACF as a theoretical lens. Conclusions and policy implications are presented in Section 6.

2. Previous Research

Numerous research has been undertaken on the role and effect of energy audits in industry, e.g., [4,20–27]. A general conclusion is that energy audits are necessary but not sufficient for improving energy efficiency in industry. Some research has also been undertaken on the role and effects of (certified) energy management systems in industry [6,28–32]. Implementation of energy management systems can contribute to energy savings, increase the adoption of low carbon practices, and improvements of carbon and economic performance of companies [33–35]. Lee and Cheng [29], on the other hand, found, in their literature review of effects of energy management systems on energy savings, that energy savings in industry decreased after implementation of energy management systems. Jovanović and Filipović [36] claimed that certified (ISO 50001) energy management standards represent a good practice of energy management in industry, but they are not the best models to improve energy efficiency. A study by Schulze et al. [37] provided evidence that the degree of energy management system implementation relates positively to companies' energy performance, but that energy efficiency could be improved by other factors not included in an energy management system, e.g., that an energy coordinator is employed. Fuchs et al. [32] found that obtaining and sustaining top management support is critical towards the success of implementing an energy management system, and that the primary barrier for success is lacking a culture of energy management. Experience from Sweden, where requirements for energy management systems were part of a voluntary agreement program for energy-intensive industries, tells that it was primarily the fact that participating companies received a tax reduction on electricity that made companies invest in energy efficiency measures, not the energy management system as such [38].

Of interest for this paper, Nabitz and Hirzel [26] found that the transposition of the original EED provisions on mandatory energy audits in large companies was delayed in more than half of the EU-28 MSs and that transposition by the MSs' results in different national implementations. One important difference was the scoping to identify which companies that should undertake energy audits. In the EED, a 'large company' is defined as the opposite to an SME, the latter which according to the EED (Article 2.26) should be defined in accordance with the EC [39] recommendation concerning the definition of micro, small and medium-sized enterprises. Some MSs focused on companies or parts of companies located in the national territory only, while others took account of parts of companies in other countries too.

In addition to scientific papers, there is some grey literature comparing the implementation of EED provisions on mandatory energy audits in different MSs of the EU. Serrenho et al. [40], Eichhammer and Rohde [41] (this study was made for the European Council for an Energy Efficient Economy (ECEEE) and paid for by Rockwool) and De Groen et al. [8] (this study was commissioned by the EC in collaboration with the Concerted Action Energy Efficiency Directive (CA EED)) analyzed MS implementation of the EED provisions, and provided some proposals for revision of the provisions, e.g., that energy use should be the criterion for mandatory energy audits. The EC [42] itself also published a report on how MSs deal with energy auditing in large companies. They found that MSs generally deal differently with multi-national and multi-site companies. Some MSs take all company parts located inside and outside their national territory into consideration for determining the status as an SME. Others rely on the company parts inside the national territory only.

The different studies on the transposition of EED provisions on mandatory energy audits in EU MSs revealed that the different approaches in different MSs led to challenges for companies. Eichhammer and Rohde [41] and de Groen et al. [8] stressed that some large companies covered have low energy use and that the costs of energy audits will not be offset by the potential savings that may arise from implementing energy efficiency measures. They proposed that obligations on energy audits should be made based on energy use, not the size of a company. Nabitz & Hirzel [26] and the EC [42] found that multi-national companies were treated differently in different MSs, with negative impacts for the level playing field on the EU internal market.

As presented, there is plenty of research on the benefits and costs of introducing energy audits and energy management systems in enterprises. The same holds true for outcomes of policy programs to stimulate their uptake. However, research on the processes and politics of policy programs for stimulating energy efficiency in industry is underrepresented in the scientific literature, cf. [10,11].

There are only a few studies focusing on the entire policy process related to energy efficiency in the EU. Both von Malmborg [12] and Dunlop and Völker [43] analyzed policy change related to the amendment of the EED in 2016–2018. Von Malmborg analyzed the advocacy coalitions, their core beliefs and paths to policy change in the EU related to individual metering and billing (IMB). IMB is a policy instruments provided by the EED to improve energy efficiency of buildings. He found that the minor coalition, opposing IMB, gathered enough support to outweigh the dominant coalition, in favor of IMB. An internal shock and policy-oriented learning led to changed provisions on IMB. Dunlop and Völker [43] analyzed an event in which the rapporteur in charge of the energy efficiency file in the EP proposed to alter the way energy efficiency is defined and measured. The meaning of energy efficiency was negotiated through the way it is technically measured. Dunlop and Völker found that processes of politicization and de-politicization in the definition of energy efficiency indicators brought about a rethinking of energy efficiency governance. In addition, von Malmborg [13] analyzed the politics of the 2021–2023 recast of the EED, with particular focus on making the 'energy efficiency first' (EE1) principle binding for MSs to apply in policy, planning, and decision-making on major investments, including in industry. There was a dispute among legislators and other stakeholders whether energy efficiency policy and the EE1 principle aimed at exploiting multiple benefits or climate change mitigation only. The multiple benefits discourse was associated with strong provisions on the EE1 principle, covering all projects in all sectors, whereas the climate change discourse was associated with weak provisions of the EE1 principle, covering very large projects only in the public sector. Deliberative negotiations enabled interdiscursive communication and policy-oriented learning across belief systems, leading to policy change in line with the multiple benefits of discourse.

3. Theory, Method, and Materials

3.1. The Advocacy Coalition Framework—A Brief Overview

This study uses the advocacy coalition framework (ACF) as a theoretical framework for analyzing the political creation of energy efficiency in EU industry. ACF is a network theory of the policy process developed by Sabatier [44–46] and Jenkins-Smith [47] in the late 1980s. It is considered one of the most influential theories for analyzing and explaining the policy process and policy change, having been applied in several hundred studies all over the world [15,48,49].

The ACF asserts that policy actors must specialize to exert any influence. This specialization takes place in policy subsystems which are defined by a policy topic (e.g., energy efficiency), territorial scope (e.g., the EU), and the actors influencing policy subsystem affairs [44]. Policy subsystems are overlapping with other subsystems and being nested within yet other subsystems [16].

Drawing on Lasswell and Kaplan [50], who describe policy as 'a projected program of goals, values and practices', the ACF argues that public policy is 'not just the actions or inactions of government, but also the translations of belief systems as manifested by goals, rules, incentives, sanctions, subsidies, taxes, and other instruments regulating any given issue' [51]. Thus, policies can be analyzed in terms of belief systems and policy change corresponds to changes in belief systems [52]. Jenkins-Smith et al. [16] argue that policy actors have a belief system structure on three levels: (i) deep core beliefs, (ii) policy core beliefs, and (iii) secondary beliefs. Deep core beliefs are normative values and ontological axioms. They can be attributed to several policy subsystems. In contrast, policy core beliefs have topical and theoretical components bound by scope and topic of the political subsystem. They can be normative and empirical, and include assessments of the severity of the problem, its basic causes, and preferred solutions. Policy core beliefs are fairly stable over time and more resistant to change than the secondary beliefs. These deal with the specific policy instruments for achieving the desired outcomes outlined in the policy core beliefs. They can be described as the actors' policy preferences, e.g., specific policy design, policy instruments, budgetary allocations, and others. These preferences are more prone to change based on new knowledge and experience [46].

According to the ACF, beliefs and behaviors of policy actors are embedded in informal networks of policy actors. Policy decisions are partly structured through these networks [53,54]. Policymakers seek to translate their beliefs into action and policies. To be successful, policy actors have to find allies for sharing resources and developing strategies. The ACF assumes that policymakers are looking for allies among people and organizations who share policy core beliefs among, e.g., parliamentarians, government officials, interest groups (IGs), researchers, and think-tanks from various levels within the jurisdiction of policy, e.g., the EU. Actors that have a significant degree of coordination form an advocacy coalition [53,54]. An advocacy coalition consists of actors in a network that share core beliefs and resources and collaborates to translate core beliefs into policy [44,45].

As for policy change, ACF aligns changes in policy core beliefs, i.e., significant shifts in the direction or goals of a subsystem, with major policy changes. Changes in secondary beliefs, i.e., changes in means for achieving the goal, e.g., policy instruments, are seen as minor policy changes [46,49]. Advocacy coalitions often disagree on proposals related to policy core and secondary beliefs, and debates on policy, therefore, focus on differing positions regarding initiatives of either change or preserve policy programs [16,54]. To understand and interpret the actions of different actors and, thus, policy change over time, one must analyze the primary and secondary beliefs of different coalitions hold [46]. ACF proposes four paths to policy change: (i) external shocks, (ii) internal shocks, (iii) policy-oriented learning, and (iv) negotiated agreements [15,16].

3.2. Notes on Method and Materials

Process-tracing is an important method in qualitative social science research, most notably in case study research designs [14,55,56]. It can be used to describe and explain policy events, and to elaborate on the paths by which they come about [55]. Process tracing can provide a rich account of 'how' a complex political phenomenon such as public policy on energy efficiency emerges. Process tracing can provide a 'how-we-come-to-know nuts and bolts for mechanism-based accounts of social change [and directs] one to trace the process in a very specific, theoretically informed way' [57,58].

There are three types of process tracing [14]: (i) case-centric, (ii) theory testing, and (iii) theory building. This study uses a combination of case-centric and theory testing process tracing. It aims at explaining outcomes in a particular case, i.e., policy to enhance energy efficiency in industry, in combination with testing a theory (propositions) derived from existing literature on ACF, energy efficiency in industry and studies of policy change on energy efficiency in the EU. Case-centric process tracing is used by researchers who assume a case to be context-specific and includes a detailed narrative explaining how a particular outcome came about [56].

Kay and Baker [14] suggested a step-by-step best practice of how to undertake process tracing as a method in policy analysis: (i) theorizing variables and empirical proxies, (ii) collecting evidence, and (iii) testing propositions (hypotheses) or presenting a detailed narrative. Based on ACF and previous research on policy change regarding energy efficiency policy in the EU, three propositions are made:

1. There exist at least three advocacy coalitions, around the EP, the EC, and the Council, respectively;
2. The EP advocates stricter and more far-reaching core beliefs in favor of energy efficiency in industry than the EC and the Council, while the Council advocates a weaker role of the public policy than do the EC;
3. Policy change followed an external shock and a negotiated agreement.

Empirical data to answer the research questions were collected by qualitative text analyses of official and confidential documents such as the (i) EC proposals for EU legislation, (ii) amendments proposed by MSs and the Council as well as the EP, (iii) non-papers and written statements of MSs, and (iv) Sweden's records and notes from negotiation meetings in the Council (particularly meetings at the level of officials (Working Party of Energy with energy attachés)) and trilogue meeting. Data were also collected from the (v) results of the EC's [59] public consultation prior to the recast of the EED, which is available with open access [60].

Sweden's reports from negotiations are confidential, explaining why positions of individual MSs and individuals cannot be revealed. They provide a unique account of the negotiations of the Council, as well as the negotiations between the Council, the EP and the EC. The authors judge the likelihood that the findings would be systematically biased is limited. Swedish officials' reporting from the negotiations should have no incentives to falsely convey the positions of other EU MSs, the EP and the EC to the Government Offices of Sweden, since this information is used to formulate Swedish negotiation strategies.

In the manual text analysis of these documents, we identified the narratives and views of various actors on energy efficiency in general and policy on energy efficiency in industry and the reasons for this. Qualitative text analysis is a suitable method in this study.It enables a thorough analysis of the material. Through text analysis, it is possible to collect material on policy making without conducting interviews or participatory observations [19].

4. Results: Advocacy on the Recast EED

Energy audits were regulated in the EU since the entry into force of the Energy Services Directive (ESD, 2006/32/EC) in 2006 (Figure 1). According to Article 6.2(a)ii of the ESD, MSs should 'ensure the availability of efficient, high-quality energy audit schemes which are designed to identify potential energy efficiency improvement measures, and which are carried out in an independent manner, to all final consumers, including smaller domestic, commercial, and small and medium-sized industrial customers'. Provisions on energy audits were made mandatory for large companies and provisions on energy management systems were added with the adoption in 2012 of the EU Energy Efficiency Directive (EED, 2012/27/EU), which also repealed the ESD. Article 8.4 of the original EED provides that MSs 'shall ensure that enterprises that are not SMEs are subject to an energy audit carried out in an independent and cost-effective manner by qualified and/or accredited experts or implemented and supervised by independent authorities under national legislation by 5 December 2015 and at least every four years from the date of the previous energy audit'. Article 8.2 of the original EED stipulated that MSs 'shall bring to the attention of SMEs, including through their respective representative intermediary organizations, concrete examples of how energy management systems could help their businesses'. In addition, Article 5.7(b) of EED requires that public bodies 'put in place an energy management system, including energy audits'.

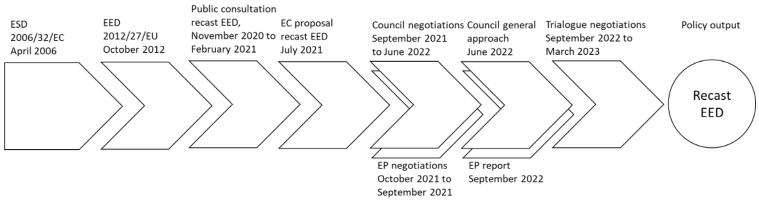

Figure 1. Development of EU legislation on energy audits and energy management systems.

4.1. The Commissions Proposal for Revised Provisions on Energy Efficiency in Industry

On 14 July 2021, the EC [7] put forward, as part of the 'European Green Deal' [61] and the 'Fit for 55' climate policy package, a proposal for a recast of the EED, repealing the original EED. The proposal included, i.a., suggestions for changing the provisions on energy audits and energy management systems in large companies (previous Article 8, new Article 11):

1. Member States shall ensure that enterprises with an average annual consumption higher than 100 TJ of energy over the previous three years and taking all energy carriers together, implement an energy management system. The energy management system shall be certified by an independent body according to the relevant European or International Standards.

2. Member States shall ensure that enterprises with an average annual consumption higher than 10 TJ of energy over the previous three years and taking all energy carriers together that do not implement an energy management system are subject to an energy audit. / . . . / The results of the energy audits including the recommendations from these audits must be transmitted to the management of the enterprise. Member States shall ensure that the results and the implemented recommendations are published in the enterprise's annual report, where applicable.'

Among the reasons for the proposal, the EC (p. 18, [7]) mentions that 'ensuring that energy audit efforts are focused on larger energy users instead of the size of companies will lead to proportionately higher energy savings, which would result in a substantial reduction in burden for businesses with a lower energy use, as well as simplifying the burden on public administrations, since they would have a simpler criterion to assess the need for audits as well as a smaller number of businesses to verify'. This was underpinned by the findings of Serrenho et al. [40] and the EC [42] studies, but also studies by Nabitz and Hirzel [26] and Eichhammer and Rohde [41], as well as the critique raised by MSs. Advocacy by the Coalition for Energy Savings and European Union Alliance for Saving Energy (EU-ASE), researchers and think tanks (e.g., Centre for European Policy Studies (CEPS), the European Council for an Energy Efficient Economy (ECEEE), and ISI Fraunhofer Institute was also important. The idea that energy use should be a criterion instead of company size was discussed in the Council during negotiations on the amending directive.

As for the proposal on energy management systems, the EC (p. 46, [7]) assumed that, 'given the importance of energy use in their business, these very largest energy users should already have more sophisticated energy management systems in place.' If not, the EC (p. 46, [7]) claims, 'it makes sense to replace the audit obligation for these businesses with one to have such a system. It is likely that most of these enterprises will be covered by the requirements of the Industrial Emissions Directive (2010/75/EU) and the obligations through it to use Best Available Techniques.' Using an environment management system is a key obligation for them, which means that implementing an energy management system would require little or no extra effort. As for resources underpinning the EC proposal, the head of unit for energy efficiency at the EC's Directorate General for Energy (DG ENER) (Personal communication with Ms. Claudia Canevari, Head of Unit, DG ENER, 24 August 2021) pointed at three sources of information; a report by Waide Strategic Efficiency Ltd. [62] prepared for the European Cooper Institute, a paper by McKane et al. [34] on quantifiable impacts of ISO 50001 on climate change mitigation, and case studies from the Clean Energy Ministerial Energy Management working group. As for energy savings of the proposal, the responsible head of unit of the EC refers to the study by De Groen et al. [8], commissioned by the EC, which estimated that the energy savings potential for non-SMEs, within the scope of Article 8.4 amounts to seven per cent of total company final energy consumption as an EU average. This corresponds to a 27 per cent reduction in energy use in industry.

4.2. Views of Interest Groups

Prior to presenting the proposal for the recast EED, the EC undertook a public consultation of issues related to the EED [60]. The objective of the consultation was to collect views and suggestions from stakeholders and citizens. The consultation did not contain any draft proposals for the recast EED, only questions on potential developments. No questions were asked about implementation of energy management systems, which indicates that this idea came later.

In total, 344 organizations and citizens provided feedback in the consultation, 257 of which presented views on mandatory energy audits. Out of these, 143 were non-governmental organizations (NGOs), including business associations (109), consumer organizations (3), and environmental organizations (3). A total of 72 companies reported views on energy audits. Ministries or national agencies of seven MSs (Czech Republic, Cyprus, Estonia, Finland, Lithuania, the Netherlands, and Spain) did respond to the questions on energy audits. As for the criteria on which companies should be subject to mandatory energy audits, 122 respondents (business associations and other NGOs, including all environmental organizations, and all MSs but one) agreed that the obligation should be based on average energy use. A total of 22 respondents, all of which were business associations or companies, disagreed. An issue discussed in the negotiations of the original EED was the frequency of energy audits. A total of 86 respondents to the public consultation disagreed that energy audits should be made more frequent than every four years, while 55 respondents thought that audits should be less frequent than every four years. A total of 70 respondents agreed or fully agreed, and 54 respondents disagreed, that energy audits should be accompanied by a requirement to disclose non-sensitive information from energy audits. Views of MSs were diverse. Finally, 118 respondents (business organizations and environmental organizations) agreed and 36 respondents (business organizations and companies) disagreed that energy audits should be accompanied by an obligation for enterprises to implement certain measures identified in energy audits. Views of MSs were diverse. This is an interesting result since the EC did not suggest such a provision, despite the prevailing view in favor of such measures. The issue was discussed in a workshop with MSs during autumn 2020, prior to the public consultation. It was stressed by many MSs that such a provision would be a violation of the freedom of companies to decide which investments should be made. However, the EC put forward such a proposal in its proposal for amending the directive on the EU Emissions Trading Scheme (ETS) Directive (2003/87/EC), stating that 25 per cent of the free allocation of emission allowances should be withheld until the most cost-effective measures identified in the energy audit were implemented.

4.3. Views of Member States and the Council

Once negotiations started, nine small and large MSs from Western, North, South, and Central EU were generally positive to the EC proposal that requirements according to paragraphs 1 and 2 are set on energy use instead of company size and ownership. Two MSs from North-Eastern Europe raised concerns about increased administration. One MS asked how MSs should identify companies, based on installations rather than companies. Along the same line, two MSs asked for a definition of enterprises since an enterprise could be made up of several entities. They also stressed that only entities within the jurisdiction of each MS should be included when identifying enterprises to be obliged by provisions in paragraphs 1 and 2. A large MS welcomed a lot of the provisions in Article 11 but asked what the 100 TJ threshold was based on, and why existing ISO standards (ISO 14001 and ISO 50001) are not mentioned. Another large MS welcomed the 100 TJ threshold in paragraph 1, whilst two small MSs considered the 100 TJ threshold too low, thus including too many companies, especially companies with low return in terms of increased energy efficiency. One MS from Northern EU suggested 300 TJ as a threshold, whilst a large MS from Central EU suggested a 1000 TJ threshold.

As for energy audits, six MSs, large and small, from across the EU claimed that the 10 TJ threshold in paragraph 2 was too low, while two MSs from Western EU claimed it was too high, since only 40 per cent of the companies would be included. An advocate of including many companies suggested a 7 TJ threshold, while of the group of MSs putting forward the non-paper during the amendment of the 2016–2018 EED advocated that less companies to be included and suggested a 36 TJ threshold. The MS proposing a low threshold would also like to see stronger provisions on reporting, while the proponent of less companies to be included suggested that reporting is made to a competent authority in order to follow up effects. One MS asked if the EC had made any calculations on how many SMEs would be included within the thresholds in paragraphs one and two. One MS thought that it should be voluntary for companies to choose between an energy management system according to paragraph 1 and an energy audit according to paragraph 2. Three MSs from Western EU, one large, one medium and one small, proposed that a provision is added in paragraph two, mandating enterprises to implement energy efficiency measures identified in energy audits. This is like the proposal by the EC that 25 per cent of free allocation of emission allowances in the EU ETS are withheld until a company undertook energy efficiency measures identified in an energy audit according to EED Article 11.2. In June 2022, the Council adopted its general agreement as input to the trilogue negotiations with the EP and the EC. As for the thresholds, the levels proposed by the EC was confirmed. In addition, the Council rejected the idea that implementation of the recommendations of energy audits should be mandatory.

In the parallel negotiations on the revision of the EU ETS directive, a majority of MSs raised the issue of free allocation, cf. [63] conditional on energy audits under the EED. Eight MSs from Central and Eastern EU were to varying degrees critical of the proposal. Three Central European MSs argued that free allocation in the EU ETS aimed to counteract the risk of carbon dioxide leakage, not to promote energy efficiency measures. In addition, not all recommendations were necessarily cost-effective; on the contrary, sometimes, it could be more efficient to make a larger investment at a later stage (such as, e.g., carbon capture and storage (CCS)). Two MSs from Central EU, thus, wondered if full allocation could be given if an operator could justify why not all measures were implemented. Another Central European MS believed that withheld free allocation was a disproportionately powerful sanction. A large MS from southeast EU believed that the energy evaluations should only be discussed within the framework of the EED. Another MS from South-Eastern EU emphasized that the recommendations should continue to be fully voluntary and questioned that they were given a more binding nature through the introduction of indirect sanctions through the EU ETS. In addition, that MS considered that the free allocation should not be changed in the current period. The EC suggestion on mandatory energy efficiency measures did not make it to the Council general approach on the amended EU ETS.

As for the Council's general approach on the recast EED, a middle ground was found among the four different coalitions, implying that medium thresholds should be applied for energy audits and energy management systems, and that recommendations from these instruments need not be implemented. No MS opposed the Council's general approach on these points. As argued by Heisenberg [19], the Council prefers to negotiate agreements rather than to proceed to voting, and that the negotiations frequently are successful in the sense that agreements are concluded.

4.4. Views of the European Parliament

Responsibility for the EED dossier in the EP lay with the Committee on Industry, Research and Energy (ITRE), who appointed Danish Member of the European Parliament (MEP) Niels Fuglsang, Group of the Progressive Alliance of Socialists and Democrats (S&D), as rapporteur. He presented his draft report (https://www.europarl.europa.eu/doceo/document/ITRE-PR-703281_EN.pdf (accessed on 8 March 2023)) in late February 2022, for voting in the ITRE. He suggested a considerably lower threshold for when energy management systems (18 TJ/year) and energy audits (3.6 TJ/year) should be implemented by companies. In addition, he suggested that MSs shall ensure that the implementation of the recommendations of energy audits is mandatory, except for those where the payback period is longer than four years.

In June 2022, the ITRE committee voted on the rapporteur's proposal for a negotiation mandate. After negotiations in ITRE, a compromise text supported by the European

People's Party (EPP), S&D, Renew Europe, and the Greens/EFA was adopted. As for thresholds, the compromise of the ITRE committee raised the levels considerably compared to the rapporteur's proposal: 100 TJ for energy management systems from 2024, 70 TJ for energy management systems from 2027, 10 TJ for energy audits from 2024, and 6 TJ for energy audits from 2027. These thresholds are higher than the rapporteur suggested but lower than the EC proposed, and the Council adopted. As for energy efficiency measures to be implemented on a mandatory basis, it is suggested that those measures with a payback period up to three years should be mandatory. The negotiation mandate of the EP was adopted when the EP voted in plenary in mid-September 2022.

4.5. Trilogue Negotiations

Informal trilogues became a standard procedure in the European Union's ordinary legislative procedure [64,65]. They provide an alternative to the formal readings back and forth between EP and Council. In trilogue meetings, the Council, the EP, and the EC are represented by negotiating delegations tasked with finding a legislative compromise between institutions. For the EP, this delegation includes the rapporteur, the shadow rapporteurs, the committee chair, and an EP vice president, whereas the Council is usually represented by the rotating presidency at the Committee of Permanent Representatives or working party level together with policy experts from the capital. The EC is represented by a director and the head of unit and policy experts from the Directorate General in charge of the dossier.

Both the Council and the EP supported the EC proposal for making energy audits and energy management systems mandatory in industry, and that requirements should be linked to firms' energy use instead of company size. However, they had different views on the thresholds for when the instruments should be implemented. The Council and the EP had different views also on implementation of energy efficiency measures identified in energy audits. The Council wanted no requirements, while the EP argued that MSs shall ensure that the implementation of the recommendations of energy audits is mandatory, except for those where the payback period is longer than three years.

Trilogue negotiations between the Council, the EP, and the EC were initiated in September 2022. Negotiations were initially going slowly as a result of deadlocked positions from both sides. Five MSs from Northern, Central, and Southern EU, both small and large, wanted to maintain the Council's general approach, but two small MSs could accept lower thresholds for the requirements. One large and one medium-sized MS from Western EU was able to support the EP proposal. After several political trilogue meetings, taking place weekly in March, the co-legislators agreed on thresholds for when energy management systems and energy audits should be implemented by companies. In the Council negotiations, MSs advocating higher or lower thresholds than the EC proposed learned and adjusted their secondary beliefs. The Council general approach proposed the same thresholds as did the EC. In trilogue negotiations, the EP adopted the secondary belief of the Council and the EC with regard to thresholds for energy audits. All institutions adjusted their views on thresholds for energy management systems, with the EP having to move the most.

5. Discussion: The Political Creation of EU Policy on Energy Efficiency in Industry

5.1. The Policy Subsystem

The ACF assumes that policy actors must specialize to be able to exert any influence, an operation taking place in policy subsystems [53]. A policy subsystem is defined by a policy topic (e.g., energy efficiency policy), territorial scope (e.g., the EU [66]), and the actors directly or indirectly influencing policy affairs [49]. Policy subsystems are semi-independent and overlap with other subsystems and are nested within yet other subsystems [16].

In this study, the policy problem relates to the question of how to promote energy efficiency in industry. There is no single EU legislation for this, why EU legislation for promoting the use of energy audits and energy management systems in enterprises in

EU MSs is used as a proxy for legislation to enable energy efficiency in industry. The EU ETS may also stimulate measures to improve energy efficiency as means to reduce greenhouse gas (GHG) emissions in companies covered by the ETS [67]. In its 2021 proposal for amending the EU ETS, the EC [68] proposed that companies covered by the ETS should undertake measures to improve energy efficiency identified in energy audits and energy management systems, in order to obtain their full allocation of emission allowances. An energy audit or an energy management system could help companies participating in the EU ETS to gain better knowledge of measures to save energy and reduce emissions. The policy subsystem of energy efficiency is, thus, linked to the policy subsystem of the EU ETS, and it is a subsystem of the larger subsystem of EU energy policy. These are linked to the even larger subsystem of EU climate policy. The proposal for a recast of the EED was a means to make the EED fit for meeting the ambitions of the new European climate law [69].

At the end of 2016, there were an estimated 0.75 million active large companies (i.e., non-SMEs), corresponding to about two per cent of all approximately 42 million companies in the EU-28 [8]. How many companies meet the energy use thresholds of the recast EED is not known, but the analysis of different options by de Groen et al. [8], which corresponds to the EC's proposal, indicates that the number of companies that will be covered by requirements for energy audits or energy management system will be drastically lower, approximately 0.15 million companies, than the number of companies covered by the original provisions.

As well as potentially 0.15 million companies with high energy use, the policy subsystem consists of energy service companies that help industry companies to undertake energy audits and implement energy management systems, the EC, the EP, MSs, the Council Presidency, national governments and parliaments, national authorities responsible for law enforcement, interest groups (business associations, environmental NGOs etcetera) on EU level and in MSs, e.g., the Coalition for Energy Savings (CfES), researchers and think tanks (e.g., Centre for European Policy Studies (CEPS), the European Council for an Energy Efficient Economy (ECEEE), Fraunhofer Institute and the Commission's Joint Research Centre (JRC) that analyzed EU legislation on energy audits and energy management systems and put forward proposals as for how to overcome the problems identified with the provisions of the original EED, are all part of the policy subsystem.

Depicting the policy subsystem as consisting of any actor attempting to influence a subsystem's affairs presents dilemma for the analyst: as mentioned, there are hundreds of thousands of actors somehow involved in the policy subsystem. A more effective approach is to organize actors into advocacy coalitions based on shared beliefs.

5.2. Advocacy Coalitions and Their Core Beliefs

An advocacy coalition consists of actors in a network that share core beliefs and resources and collaborates to translate core beliefs into public policy [43,44].

Based on text analysis of MS non-papers, amendments suggested and notes from negotiation meetings, ten core beliefs were identified (Table 1), many of which are negations of each other.

As argued by Byskov-Lindberg and Markard [70], the identification of core beliefs is a challenging task in studies of EU policy. This is particularly true for core beliefs of EU MSs, since countries do not hold core beliefs that hardly change over time. The positions of an MS are often the result of negotiations within the country, and it can change with the next election. In addition, MS positions within negotiations might not be clear until the end of the negotiations when decisions are voted on in the Council. In all, Byskov-Lindberg and Markard [70] argue that the 'treatment of MSs in the ACF and the operationalization of their policy core beliefs represents a conceptual challenge of the ACF on international/supranational levels, which has not yet been adequately addressed in the literature'. The core beliefs presented in Table 1 represent core beliefs presented in the period from 2021 to 2022. No changes in beliefs of MSs over time were accounted for.

Table 1. Core beliefs identified among actors in the policy subsystem (policy beliefs are grouped in relation to views on the strength of EU policy on energy efficiency in general (policy core beliefs) and related to energy efficiency in industry (secondary beliefs)).

Strong EU Policy	**Weak EU Policy**
Deep core beliefs	
EU policies should mandate companies to make certain investments.	Companies should have the freedom to decide themselves which investments to make.
Policy core beliefs	
Increased energy efficiency is the first fuel and vital for reaping multiple benefits.	Increased energy efficiency is vital for mitigating climate change and enhancing energy security of supply.
EU policy should have binding policy measures for energy efficiency.	There should be flexibilities for MS to decide how targets are met.
Companies should be obliged to undertake energy efficiency measures identified in their energy audits.	Companies should not be obliged to undertake energy efficiency measures identified in energy audits.
Secondary beliefs	
The thresholds for when companies should implement energy audits or energy management systems should be low. Many companies should be obliged.	The thresholds for when companies should implement energy audits or energy management systems should be high. Few companies should be obliged.

Actors' policy beliefs and behaviors are embedded in informal networks and policy decisions in the policy process are structured by policy actors through these networks [53]. Policymakers seek to translate their beliefs into action and real policy. To be successful, policy actors must find allies and form advocacy coalitions.

Table 2 presents networks of actors, i.e., advocacy coalitions, identified based on core beliefs of actors held in relation to energy efficiency in industry. Four coalitions were identified, with beliefs of MSs being divergent. One small and one medium MS from Western EU shared core beliefs with the EP, wanting strong EU policy. On the other hand, a group of six small, medium, and large MSs from Central, Southern, and Northern EU argued for weaker EU policy. The Council's general approach was in line with the EC proposal regarding thresholds for when companies should implement energy management systems and energy audits. The EC did not suggest provisions on implementation of measures identified in energy audits in the recast EED, but in the amended EU ETS, why it shared beliefs with a large MS from Western Europe. As for the criteria on which companies should be subject to mandatory energy audits, 122 respondents to the EC public consultation (business associations and other NGOs, including all environmental organizations, and all MSs but one) agreed that the obligation should be based on average energy use. An amount of 22 respondents, all of which were business associations or companies, disagreed. In addition, 118 respondents agreed, and 36 respondents disagreed, that energy audits should be accompanied by an obligation for enterprises to implement certain measures identified in energy audits.

Table 2. Advocacy coalitions (actor networks) of different actors in the subsystem.

	Threshold for Implementation of Energy Audit and/or Energy Management System		
Mandatory implementation of recommendations	**High**	**Medium**	**Low**
Yes	n/a	European Commission, one large MS, 118 interest groups	European Parliament, two small and medium-sized MSs
No	Six MSs	Council, other MSs *, 36 interest groups	n/a

* Note that views of MSs in the Council are divided, but the Council's general approach focuses on a medium threshold and no mandatory requirements to implement recommendations from energy audits and/or energy management systems.

As König and Junge [71] suggested, we need to examine more closely the relationship between EC proposals and agenda-setting, on the one hand, and how the EC exploits potentially favorable coalitions in the Council, on the other [17]. The ACF research program hypothesizes that unofficial policy actors, i.e., actors within purposive groups, are more constrained in their expression of beliefs and policy positions than actors from material groups such as MSs, the EC, and the EP [16]. This hypothesis is rarely tested. This study found no support for this hypothesis, as unofficial policy actors such as think tanks (e.g., CEPS, ECEEE, JRC) had the ear of the EC and provided data for the Commission to underpin its proposals. They were explicit in their recommendations for policy. The coalition formed during negotiations on the amended EED, calling for energy use to be defining which companies should undertake energy audits largely remained intact, was now also calling for a higher threshold than what the EC suggested. As for the coalition including the EC, only one large Western MS shared the same beliefs, but also a majority of interest groups. The majority of MSs shared the EC view on a medium threshold but did not share the belief that recommendations from energy audits and energy management systems must be implemented (to get a higher share of free allowances in the EU ETS). Two MSs shared the view of the EP on strong policy in both regards. The main reason the coalition formed around a medium-sized MS from Northern EU did not get more support was that MSs did mainly focus on other parts of the EED in the Council negotiations, i.e., provisions on the EU headline target and national contributions in Article 4, and the national energy savings obligations in Articles 8–10. Energy efficiency in industry was not the main issue at stake, and most MSs took the fight on other, to them, more important issues of the recast EED related to their policy core beliefs rather than their secondary beliefs.

5.3. Paths to Policy Change

The ACF model proposes four paths to policy change: (i) external shocks, (ii) internal shocks and other internal events in the political subsystem, (iii) policy-oriented learning, and (iv) negotiated agreements [15,16]. ACF provides the hypothesis that at least one of these, or any combination thereof, is a necessary but not sufficient source of change in the core beliefs and attributes of a policy program. Another hypothesis of ACF is that the policy core attributes of a policy program will not be significantly revised if the advocacy coalition that instated the program remains in power—unless a change is imposed by a hierarchically superior jurisdiction.

Policy changes in the subsystem related to energy audits, energy management systems, and energy efficiency in industry followed several paths which are discussed below. The policy change related to the new definition of which companies should undertake an energy audit could be seen as a minor change, although with high impact for companies, national authorities and the level playing field on the EU market, whilst the new requirement for companies with higher energy use should implement certified energy management systems is a major policy change. The latter provision puts new requirements on industry.

5.3.1. An External Shock

External shocks include events outside the control of subsystem actors, in terms of their ability to influence underlying causes and triggers [16]. They are changes in the socio-economic conditions, changes in the governing coalition or policy decisions from other political subsystems. They increase the likelihood of major policy change. However, they require enabling factors, e.g., raised public and political attention, agenda change, and a redistribution of coalition resources and opening and closing of political venues, for policy change to happen [16].

The current EC, led by President Ursula von der Leyen, entered office on 1 December 2019. Soon thereafter, on 11 December 2019, the EC put forward a proposal for a 'European Green Deal' [61], aiming to promote a fair and prosperous society with a modern, resource-efficient, and competitive economy with net zero emissions of GHG by 2050. As part of the Green Deal, the EU adopted a new climate law in March 2021. The European climate law established the EU climate targets for reducing GHG emissions to 55 per cent to 2030 compared to 1990 levels and climate neutrality, i.e., net zero emissions, in 2050. To meet the new 2030 GHG target, and as part of the 'European Green Deal', the EC put forward, on 14 July 2021, a package of proposals to make the EU's climate, energy, land use, transport, and taxation policies 'Fit for 55' (https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3541 (accessed on 7 December 2022)). Achieving these emission reductions in the next decade is crucial to Europe becoming the world's first climate-neutral continent by 2050 and making the European Green Deal a reality. With the package, the EC presented 'the legislative tools to deliver on the targets agreed in the European climate law and fundamentally transform our economy and society for a fair, green and prosperous future'.

The EC's proposal on mandatory energy audits and energy management systems, which is part of the proposal of a recast EED, can, thus, be seen as a consequence of the 'European Green Deal' and the new climate law, decided on in another policy subsystem. The decision on changes to the EED are dependent on decisions in the policy subsystem for climate policy. In all, the policy change related to the EED, including energy audits and energy management systems, could be seen as a consequence of an external shock. However, it is mainly that there is a change made to the policy that follows the climate law, not which policy changes were made. In comparison, the new, more ambitious EU target on energy efficiency to 2030—raised from at least 32.5 per cent to 36 per cent regarding final energy use and 39 per cent regarding primary energy use—set by the recast EED—is a more direct consequence of the 'European Green Deal' and the climate law and, thus, a result of an external shock, as is the decision on more ambitious national energy savings obligations—with an increase from 0.8 per cent new annual energy savings to 1.5 per cent new annual energy savings. That EU provisions on energy audits (and energy management systems) should be amended was decided already in the amendment of the EED in 2018.

5.3.2. A Negotiated Agreement

The new legislation is a negotiated agreement—a result of deliberative negotiations in the Council and the EP, and trilogue negotiations between the EP, the Council, and the EC. Negotiated agreements mean that the policy change does not correspond to the policy goals of the dominant or minority coalition, but a negotiated middle ground. Negotiated agreements may emerge in a variety of ways but are facilitated by collaborative institutions conducive to negotiation. This is the case of EU decision making, with co-decision of the Council and the EP on new, amended, or recast directives and regulations [17].

As for the Council general approach on the recast EED (see Section 4.3), a middle ground was found among the four different coalitions, implying that medium thresholds should be applied for energy audits and energy management systems, and that recommendations from these instruments need not be implemented. No MS opposed the Council's general approach on these points. As argued by Heisenberg [19], the Council prefers to negotiate agreements rather than to proceed to voting, and that the negotiations frequently are successful in the sense that agreements are concluded. The Council's general approach in this case was met in the Permanent Representatives Council some days ahead of the Council of energy ministers' meeting on 27 June 2022. The Council's general approach was met through deliberation, convincing others of the right thing to do through the force of the better argument. However, it is hard to generalize on the status of the Council as a deliberative body. Deliberation sometimes happens, under specific circumstances. In particular, the level of politicization is important [17]. The issues at stake regarding energy efficiency in industry were not the main issues at stake in negotiations on the recast EED, rather the EU energy efficiency target and national contributions and national energy savings obligations. As for negotiations in the EP, a compromise text was agreed upon by S&D, EPP, Renew Europe, and the Greens/EFA before voting in the ITRE committee and then in the EP plenary.

Both the Council and the EP supported the EC proposal for making energy audits and energy management systems mandatory in industry, and that requirements should be linked to firms' energy use instead of company size. However, they had different views on the thresholds for when the instruments should be implemented, thus explaining why trilogue negotiations were slow at the start. The Council and the EP had different views also on implementation of energy efficiency measures identified in energy audits. The Council wanted no requirements, while the EP argued that MSs shall ensure that the implementation of the recommendations of energy audits is mandatory, except for those where the payback period is longer than three years. After deliberative trilogue negotiations, the EP adopted the secondary belief of the Council and the EC with regard to thresholds for energy audits (10 TJ annual energy use). All institutions adjusted their views on thresholds for energy management systems (85 TJ annual energy use), with the EP having to move the most. In addition, they agreed that companies should not be mandated to undertake energy efficiency measures identified in energy audits, which was the Council position. The EP gave up its policy core belief that companies should invest in energy efficiency measures with a pay-back time up to three years after the Council Presidency explained the deep core belief of the Council that companies are free to decide on what investments to make.

Contrary to the findings of Brandsma [64] and Reh et al. [72], that an increasing number of co-decisions by the EP and the Council are met informally and secluded by fast-track agreements before the EP and the Council adopted their negotiation mandates, so-called first reading agreements, the agreement on the recast EED was met as a second reading agreement. Both the EP and the Council adopted their negotiating mandates before trilogues commenced. Nevertheless, it was an early agreement, following an informal and secluded process. Under co-decision, informal decision making is in line with the Lisbon Treaty. Informal decision makingplays along within the EU's formal legislative process, from which it differs along three dimensions: (i) a restricted, noncodified set of decision makers operates in a secluded setting, (ii) social interaction is structured by informal rather than codified and enforceable rules, and (iii) informal compromise must be legitimized through the formal process of rubber stamping [64,72]. In the case of energy efficiency in industry, part of the recast EED, there were high expectations for early agreements on all legislative acts in the 'Fit for 55' package, with the 'European Green Deal' being one of six priorities of the von der Leyen Commission.

The mode of negotiation to be found in decision-making processes of the EU is determined by context [73]. It is demonstrated empirically that most negotiations in the EU are to a large extent problem-solving exercises, as was the case on energy efficiency in industry. Under certain circumstances, however, conflictual bargaining occurs. The pattern varies with level of politicization and type of policy, and according to the stage in the decision-making process [73].

5.3.3. Policy-Oriented Learning

The deliberative nature of the negotiations opened for policy-oriented learning in the political subsystem for energy efficiency. Policy-oriented learning is defined as 'enduring alternations of thought of behavioral intentions that result from experience and concerned with the attainment or revision of the precepts of the belief system of individuals or of collectives' [74]. Learning implies changes in belief systems of advocacy coalition members that include the understanding of a problem and associated solutions, as well as use of political strategies for achieving objectives [16]. Through learning, policy actors can maintain, reinforce, or revise their beliefs about the patterns and outcomes of policies. First, there was 'epistemic learning' from experiences, cf. [75], driven by documented experiences from MSs, scientific research, and science-based experts, that a focus on large enterprises was hard to deal with administratively, which resulted in a change of the provisions on energy audits. In epistemic learning, knowledge is deployed by a limited set of expert actors to narrow discussion with the aim of reaching a technical policy solution [76]. Dissatisfaction with the performance of the original provisions on energy audits—in terms of either its policy outputs at the operational level or its resulting inability to deal with the problem—led program proponents to reexamine their policy, cf. [45]. New knowledge, mainly from consultants but also from scientific research, also led to mandatory requirements for implementation of energy management systems in companies with highest energy use.

Second, there was 'reflexive learning across belief systems', cf. [45,74,75]. Reflexive learning appears when the degrees of problem tractability and certification of actors are low [75]. In reflexive learning, knowledge is employed with the aim of deepening discussion and facilitating argument. Reflexive learning is often regarded as 'deep' or 'complex' because it is the mechanism through which policy actors adjust their strategies and explore their fundamental preferences and identities [75]. Reflexive learning is the outcome of a social relation within a community of actors or a network, sometimes across advocacy coalitions with diverging belief systems. 'Deliberative' is arguably the most pure or ideal-typical form of reflexivity, where learning is not deduction, but the outcome of a process of communication, persuasion, and invention. According to ACF, policy-oriented learning can appear across belief systems and advocacy coalitions. When two cores conflict, the tendency is for 'each coalition to talk past the other and, thus, for a "dialogue of the deaf" to persist until external conditions dramatically alter the power balance within the subsystem' (p. 155, [45]). The task for policy analysts is to identify the conditions under which a productive debate between members of different advocacy coalitions is likely to occur. The indicator of such a debate is that one or both coalitions are led to alter policy core beliefs, or at least important secondary beliefs, as a result of an observed dialogue rather than a change in external conditions. MSs were part of four different advocacy coalitions, but they found a middle ground with the Council's general approach that medium thresholds should be applied for energy audits and energy management systems, and that recommendations from these instruments need not be implemented. MSs in the Council learned from each other and accepted the core beliefs of the middle-ground positions. There was no voting in the Council and no MSs openly opposed the core beliefs expressed in the Council's general agreement once it was decided. The situation was similar to the EP ITRE committee, where proposals of the supporting parties were taken onboard the compromise text without conflict. As for the trilogues, an agreement was reached on thresholds for energy audits (10 TJ annual energy use) and energy management systems (85 TJ annual energy use), and that companies should not be mandated to undertake energy efficiency measures identified in energy audits, which was the Council's position. This policy-oriented learning across belief systems occurred since there was an intermediate level of informed conflict between the different coalitions. Everyone had the technical resources to engage in debate, and the conflict was between important policy core and secondary aspects of the different belief systems, cf. [50]. In addition, there existed a forum in the Council and the EP and the trilogues that was prestigious enough to force professionals from different coalitions to participate and dominated by professional norms.

The different policy options put forward by the EC and the EP created dualities between related but incompatible frames (beliefs), one supported by the EC and the Council and one supported by the EP. Acting as a policy broker [76] in Council negotiations and trilogue negotiations, the rotating Council Presidency utilized 'frame polarization' and 'frame disconnection' to find a compromise between the competing policy proposals, cf. [77] (Figure 2). The first strategy involves making the difference bigger by reaffirming a possibly upgraded version of your own policy as well as criticizing the opposite framing. The second strategy means disconnecting the challenging element from the ongoing conversation as irrelevant, unimportant or the like. The EP in turn reacted through 'frame incorporation', and 'frame disconnection'. Frame incorporation implies incorporating a downgraded reformulation of a challenging element (no requirements for investments based on outcomes of energy audits).

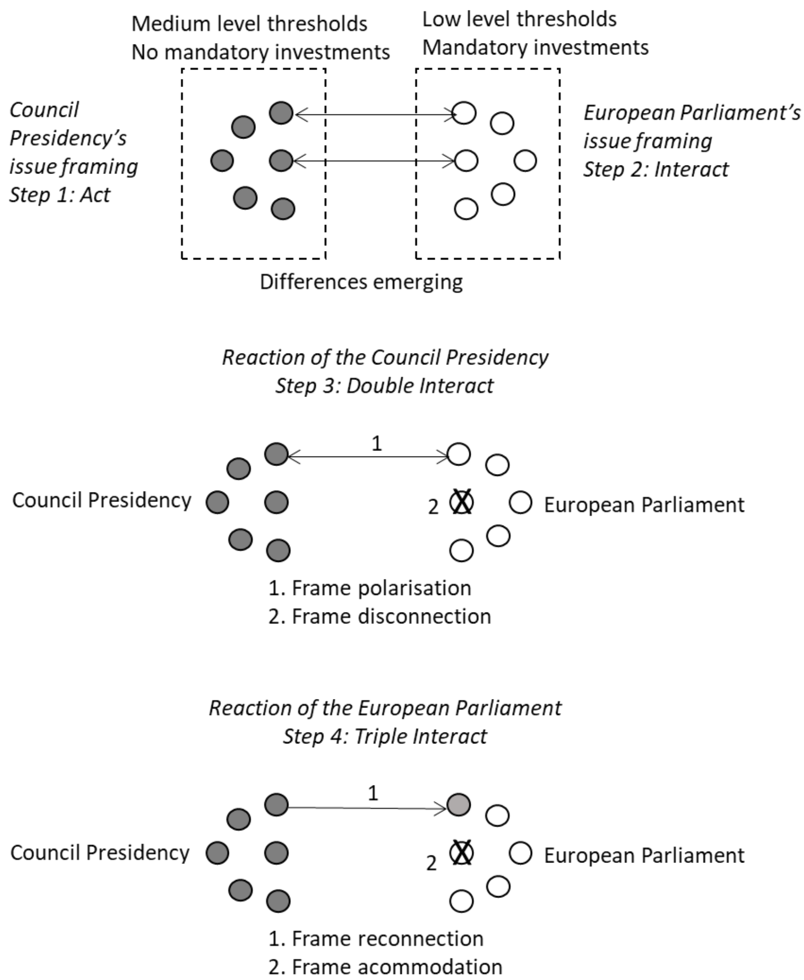

Figure 2. Discursive interaction strategies to deal with dualities in reflexive learning across belief systems. Based on Dewulf & Bowen [77].

6. Conclusions and Policy Implications

This paper set out to analyze the political processes related to the change of EU legislation on energy efficiency in industry. Three propositions were made:

1. There exist at least three advocacy coalitions, around the EP, the EC, and the Council, respectively;
2. The EP advocates stricter and more far-reaching core beliefs in favor of energy efficiency in industry than the EC and the Council, while the Council advocates a weaker role of the public policy;
3. Policy change followed an external shock and a negotiated agreement.

It is concluded that four different advocacy coalitions were formed, not three as stipulated, each including one or more MSs. The Council, the EC, and the EP had different deep core beliefs, policy core beliefs, and secondary beliefs, and were part of different coalitions, the Council being part of the dominant coalition. The resulting policy change was due to an external shock to the policy subsystem of energy efficiency in industry, i.e., the adoption of a new climate law in the EU with new climate targets for 2030 and 2050 which required a recast of the EED, calling for change of the energy efficiency legislation to be 'fit for 55'. It was also a result of negotiations in the Council, the EP and between the Council, the EP, and the EC. Negotiations in the Council, the EP and between the Council, the EP, and the EC were of a deliberative nature, meaning trying to reach agreement through the force of the better argument. The deliberative nature of negotiations opened for policy-oriented learning across belief systems. MSs in the Council learned from each other and accepted the core beliefs of the middle-ground positions. There was no voting in the Council and no MS openly opposed the core beliefs expressed in the Council's general agreement once it was decided. Policy-oriented learning took place also in the trilogue negotiations between the Council, the EP, and the EC.

As for policy implications, it was found that the EC proposal on mandatory implementation of energy management systems in industry was poorly backed up with scientific research despite its existence. This calls for policymakers to become better in justifying their proposals for new or amended policy.

In addition, the thick description of the processes of policymaking provide knowledge for stakeholders of different kinds on how policymaking in the Council and the EU takes place. The paper gives scientists and stakeholders a glimpse into the private and somewhat 'confidential' means of communication with the other side, which usually characterize negotiations in the Council [18,19] and between the Council and the EP. This knowledge can help policymakers and stakeholders better shape their strategies in future advocacy and policymaking. The identification of core beliefs and advocacy coalitions will help policymakers and other stakeholders become more aware of their own and others' values on energy efficiency and how these could be changed. As important is the differentiation of deep core beliefs, policy core beliefs, and secondary beliefs. Which beliefs can be easily changed, which cannot?

As for future research in energy policy, it is important to study the implementation of the revised EU policy in different MSs. Are the new provisions easier to apply? How is the level playing field on the EU internal market affected? As for energy management research, also relevant for energy policy, it is important to analyze how the new EU provisions affect energy management in European enterprises. Do levels of energy use decrease?

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