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Development of the Implementation of Renewable Sources in EU Countries in Heating and Cooling, Transport, and Electricity

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Abstract: This paper compares the use of renewable energy sources (RESs) in the EU, focusing on their application in the transport, cooling and heating sectors and electricity production. It examines the current situation in the EU and assesses to what extent their laws and policies have contributed to the transition to renewable energy sources. This study focuses on several forms of renewable energy, including solar, wind, hydro energy, and biomass energy. The analysis is based on several variables, including production, consumption, and environmental impact. The findings of the analysis highlight the contrasts and similarities between the two nations and illuminate the best strategies for advancing sustainable energy development. This study also analyzes the main renewable energy strategies and policies to understand which factors support or hinder the transition to sustainable and clean energy. The analysis underscores the importance of optimizing energy efficiency and achieving long-term savings using RESs. Additionally, this study emphasises the role of RESs in enhancing energy security and promoting economic growth through technological innovation. This study also highlights the potential of RESs to reduce emissions in industry, transport, and agriculture, thereby contributing to environmental sustainability. The results show that the use of renewable energy sources (RESs) in the European Union has increased in the analyzed period. The results of this study can be useful to government agencies, businesses, academia, and the public interested in supporting the development of sustainable energy in the EU.

Keywords: energy policy; renewable energy sources; biomass; energy production; living environment; EU

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1. Introduction

To combat climate change, renewable energy has become a key objective of the European Union (EU). The EU has set aspiring goals to decrease our carbon footprint and to support a clean and green future by transitioning to the use of renewables. This contribution aims to analyze the role that renewables have in the EU and the EU's policy and legislation support in individual Member States. The findings provide an overview of the best methods to support the growth of sustainable energy sources while pointing to different successful transitions in different Member States.

Although the individual EU countries have achieved different degrees of success in supporting RESs, the examination and comparison of the EU strategy identify the best practices for sustainable energy development. The key element of energy security is the

decrease in the dependence on fossil fuels, which boosts economic development and creates new job opportunities in the renewable energy industry.

Considerable focus has been placed on advancements in renewable energy sources, including energy storage solutions, the creation of new technologies, and enhancing their efficiency. Investments from abroad in renewable energy sources are crucial for funding innovative solutions and gaining access to new technologies which enhance the integration of renewable energy sources into energy systems. Therefore, the evaluation of renewables in the EU is very important. Examining the European Union's policy and legislative measures provides a deeper insight into its responses to energy challenges and allows for the identification of those strategies that have proven to be successful in the development of different types of renewable energy sources.

The axiom illustrates that Member States' cooperation can speed up the transition to renewables and support Europe's overall ecological transformation. Growing enthusiasm for renewable energy can be observed in both political and economic arenas as well as in cultural trends. Advancements in new technologies and the formulation of ecological solutions are becoming integral to contemporary living. Consumers permanently raise their expectations and view the selection of sustainable energy sources as a key aspect of their way of life.

This strategy creates a new cultural space where understanding renewable energy sources, their benefits, and their environmental impacts presents an essential trend. EU policies in the renewable energy sector reveal opportunities to assess not only technical approaches but also the support provided to these resources via legislative initiatives and global partnerships. The evaluation of RES use demands consideration of economic, political, and social problems [1]. The selection of indicators depends on the fact that heating and cooling systems play a decisive role in the integration of renewables' use [2]. The aim of this paper is to fill in the information gap that represents one of the main obstacles to the faster development of RESs in selected industrial segments. This analysis provides important insights into how the EU is addressing energy challenges and which strategies best support the transition to sustainable energy. The use of renewable resources is examined from the perspective of the percentage of RES use for electricity generation in the heating/cooling, transport, and electricity sectors, as well as in the overall energy mix of individual countries.

2. Literature Review

Researchers have studied the historical development of RES use from the perspective of implemented promotional strategies and financial support. According to Haas et al., technology-specific financial assistance for RES-E technologies has proved to be far more effective and efficient than alternative measures [3]. Hence, it is not all about the common question of feed-in tariffs vs. quota systems based on tradable green certificates but more about the design criteria of implemented RES-E support schemes. Colmeran-Santos et al. studied the future orientation of RES use, projecting the achievement of the Europe 2050 low-carbon scenario based on renewables and incorporating highly renewable and efficient electricity systems, which would influence energy demand [4].

Government policies, as well as public opinions, influence RES use. Zhang et al. analyzed public sentiment towards various renewable energy sources to identify potential policy improvements [5]. Their study revealed a declining interest in geothermal energy and a growing interest in biomass energy. Biomass energy garnered the highest positive sentiment, while solar and wind energy attracted the strongest public interest. Given these findings, solar and wind energy appear to be the most promising options for future energy transitions.

A number of studies have dealt with renewables' use for electricity production. An example is that of Huterski et al., finding that northern EU countries have a favourable situation [6]. The study also highlighted problems with the ecological production of electricity in several EU Member States. Gökgöz and Güvercin found special differences in chosen EU countries from the perspective of average effectiveness [7]. While Sweden, Germany, Spain, Belgium and Romania are leaders in effectiveness, prevalent energy producers limit renewables' use, such as France and United Kingdom. Average source productivity increases annually by 8.4%. This plays an important role in analysing the level of renewables' effectiveness and energy policy of the states. Bogdanov et al. showed RES use in the Japanese energy system, trying to reveal a new mixture of technologies, including both multi-regional and multi-sectoral energy systems [8]. Such a system could contribute to the defossilisation and improvement of energy system flexibility. The study found that Japan has undergone rapid defossilisation, building a self-sufficient renewable energy system. In China, according to Yu et al., four kinds of renewables present an optimal mix: hydropower, wind, PV, and biomass [9]. Their study showed the change in RES use over time; in 2022, the most used renewable was hydropower, and the least used was biomass. By 2030, China expects this to change, with the highest rate of change occurring for photovoltaic energy.

As pointed out by Bogdanov et al., multi-sectoral analysis of RES use is important as well [8]. A number of studies have approached this from the technological point of view. A number of authors, such as Janiszewska and Ossowska, have investigated the use of distinct renewable energy sources, specifically agricultural biomass available in European Union Member States for energy applications [10]. Their research clearly indicates that EU countries possess considerable agricultural biomass potential. However, due to the high demand for such sources in agriculture, only 15% of biomass' existing potential is used. This presents a vast difference in agricultural biomass potential in EU countries, which can have a negative influence on the economic efficiency of the use of this type of renewable. Liu et al. studied the energy needed to cool and heat buildings [11]. Their study shows that geothermal energy is broadly used due to its ease of access and low influence on the environment. Solar heating and cooling systems represent a promising technology as well, as Buonomano et al. (2018) found an increase in this renewable energy in the building sector [12]. Their study shows the differences between European zones. This underlines the aim of this paper, which is to assess RES use in individual EU countries. Massaro et al. studied use of wind and hydropower renewables in the Italian electrical system and found successful applications [1]. Habermeyer et al. considered biomass as a transport fuel, carrying out a techno-economic analysis [13]. Kohne et al. studied the potential use of waste for energy, aiming to find energetic, economic, and ecological waste's potential and current use [2]. Mohammadrezaei et al. employed energy balance calculations and fluid dynamics simulations to determine the optimal mechanical stirrer rate for biogas reactors [14]. Their research highlights the technological dimension of RES utilization. According to Fabre et al., an optimal energy blend of mineral-intensive renewable energy and fossil fuels was created, which indicated that a higher recycling rate of minerals prompts the greater reliance of the energy mix on renewables [15].

As reported by Maggio et al., there has been a notable increase in renewable energy production; however, this growth has led to a discrepancy between supply and demand due to the accessibility of these energy sources [16]. The aforementioned factor causes certain problems, such as balancing the electrical net, mainly during the use of excess energy. Hydrogen from renewables will be a viable and competitive solution, together with the creation of a new energy market. It results from a situation in which the rate of grid expansion and flexibility cannot match the rate of renewables' growth [17]. Therefore,

it is necessary to prepare the whole energy system to meet oversupply from intermittent renewable energy sources. In this connection, Gudmundsson et al. found that the optimal energy storage of renewable energy can be achieved in the heating sector by combining fuel with utility-scale heat pumps, electric boilers, and large thermal storage [18]. This is the reason we chose to evaluate the heating and cooling sector. Therefore, to enhance RES utilization, substantial investments, radical innovation, and improvements to existing technologies are necessary. Kerr et al. support the idea, suggesting that research and development efforts in the renewables sector could present significant expected value in future revenue support [19]. A review of the mentioned literature is given in Table 1 to support the need to study RES use.

Table 1. Summarizing table of selected previous studies of RES use.

Author, Year	Key Themes, Methodology	Findings and Conclusions
Colmeran-Santos et al. [4]	RES use orientation according to Europe 2050	Highly renewable and efficient electricity systems influence energy demand
Zhang et al. [5]	Public approach to RES use	There is declining interest in geothermal energy and growing interest in biomass energy, with solar and wind energy having the strongest public interest
Huterski et al. [6]	RES use for electricity production	Northern EU countries have the most favorable conditions and several countries have problems with ecological production
Gökgöz and Güvercin [7]	Average effectiveness of RES use	There are differences in chosen EU countries
Bogdanov et al. [8]	RES use outside Europe (Japan)	A new technology mix will involve multi-regional and multi-sectoral energy systems
Yu et al. [9]	RES use outside Europe (China)	Hydropower is the most used renewable and biomass the least, and photovoltaic is expected to have grown the most by 2030
Janszewska and Ossowska [10]	Technological point of RES use in agriculture	EU countries possess considerable agricultural biomass potential
Liu et al. [11]	RES use in the cooling and heating sector	Geothermal energy is broadly used, and solar heating and cooling systems present a promising technology as well
Buonomano et al. [12]	RES use in cooling and heating in the building sector	There are differences in European countries
Massaro et al. [1]	RES use in Italian electrical system	Italy has had successful applications
Habermeyer et al. [13]	RES use in transport	Biomass has potential as a transport fuel
Kohne et al. [2]	Waste use for energy	Waste has energetic, economic, and ecological potential
Mohammadrezaei et al. [14]	Biogas use	The optimal energy balance and fluid dynamics of biogas reactors
Fabre et al. [15]	Optimal energy blend of RES and fossil fuels	A higher recycling rate of minerals prompts a greater reliance of the energy mix on renewables
Maggio et al. [16]	RES energy production	There has been a notable increase and discrepancy between supply and demand due to the accessibility of RESs
Lee et al. [17]	Use of hydrogen as an RES	Creation of a new energy market is necessary
Gudmundsson et al. [18]	RES energy storage	Optimal storage in the heating sector is possible through combining fuel with RESs
Kerr et al. [19]	RES technologies and revenue development	There are significant expected future revenues

3. Methodology

In this research, we used primary and secondary data, together with a review of public reports and data. To reveal parallels, contrasts, and variables that have helped or hindered the development of renewable energy sources, this study will also include a comparative examination of the two countries.

The research process consists of the following steps:

1. Carrying out a literature search to obtain more information about the laws and programs that are in place to support the use of RES, as well as about the current state of the renewable energy industry in Slovakia and Spain.
2. Reviewing statistical data on the availability and share of RES in the overall energy mix of Slovakia and Spain.
3. A comparative analysis of the two countries to see what they have in common, what they do not have in common, and what factors have helped or hindered the growth of the renewable energy industry.
4. Drawing conclusions and presenting proposals to stakeholders, industry experts, and politicians in both countries.

Overall, it can be concluded that the research techniques used in this study will provide a thorough and comparative review of the growth of RES in Slovakia and Spain and offer insightful advice for the transition to more sustainable energy systems.

Both primary and secondary sources will be used in this research. Interviews with industry experts will be used as primary sources to gain more insight into the potential and challenges facing the renewable energy sector in both countries, as well as the effectiveness of policies and initiatives. As secondary sources, published reports and data will be used, which will be reviewed to learn more about the laws and programs that are in place to support the use of RESs, as well as the current state of the renewable energy industry in Slovakia and Spain. This study also compares the two states to determine parallels, differences, and elements that have helped or hindered the growth of the renewable energy industry.

The evaluation of data using statistical techniques such as descriptive statistics (mean, median, and standard deviation) and inferential statistics (hypotheses, *p*-values) is called statistical analysis. This makes it easier to spot trends, patterns, and differences in the data. To better understand data and explain findings, data visualization involves constructing graphs and visualizations (such as histograms, scatter plots, and bar charts). Finding patterns and anomalies is easier thanks to visual presentations.

The research demanded consideration of the RES legislation in the EU.

The European Union has created a complex set of legislation governing the development and implementation of renewable energy sources. Key legislative acts include the following.

Renewable Energy Directive (2009/28/EC https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex:32009L0028, accessed on 13 January 2025): this is a key directive that sets binding targets for all EU countries regarding the total share of energy from renewable sources in energy consumption by 2020.

Energy Union governance and climate action (Regulation EU/2018/1999 https://eur-lex.europa.eu/eli/reg/2018/1999/oj/eng, accessed on 13 January 2025): this regulation establishes a framework for the governance of common energy and climate objectives, including the integration of renewable energy sources.

Renewable Energy Directive (EU/2018/2001 https://eur-lex.europa.eu/eli/dir/2018/2001/oj/eng, accessed on 13 January 2025), presented as part of the package "Clean Energy for All Europeans", was decreed for the creation of more stable and favorable environments for the development of energy from renewables after 2020.

2030 Climate and Energy Frameworks: these include EU-wide targets and policy objectives for the period 2021 to 2030 to ensure that the EU meets its energy and climate targets.

The Green Deal presents an action plan to ensure the sustainability of the EU economy through climate and environmental policy.

Energy Efficiency Directive (2012/27/EU https://eur-lex.europa.eu/eli/dir/2012/27/oj/eng, accessed on 13 January 2025): although primarily focused on energy efficiency, this directive indirectly supports the deployment of renewable energy by reducing overall energy demand.

Electricity Market Regulation (2019/943 https://eur-lex.europa.eu/eli/reg/2019/943/oj/eng, accessed on 13 January 2025): This regulation aims to integrate national electricity markets into the EU single market. It contains provisions that facilitate greater integration of renewable energy.

The Electricity Directive (2019/944 https://eur-lex.europa.eu/eli/dir/2019/944/oj/eng, accessed on 13 January 2025) exists within the framework of the Clean Energy for All Europeans package. This directive sets out rules to empower consumers and create a fairer market, which in turn can support renewable energy sources by allowing consumers to produce and sell their own energy from renewable sources.

The EU Heating and Cooling Strategy is orientated to increasing energy use from renewables in the heating and cooling sector, thereby reducing emissions and increasing efficiency.

Each of these legislative acts and policy frameworks sets out specific objectives, guidelines, and mechanisms with which EU Member States can promote and develop renewable energy sources within their national contexts [20,21].

The European Union has important renewable energy (RE) goals in order to meet commitments under the European Green Deal and the Paris Agreement. The goal is to achieve climate neutrality by 2050. This can be accomplished by increasing energy consumption from renewables by 20%, which will create space for a possible further increase in targets. In 2018, the redistribution of other Member States was reassessed in the RES Directive in order to supply energy to this directive, and a new binding target in the field of RES was adopted by 2030, namely a share of up to 32%. In response to rapidly changing geopolitical and climate conditions triggered by the REPower EU plan and aggressive measures to end dependence on Russian fossil fuels, the 2023 target was raised again. The share of energy from renewable sources to be achieved in 2030 was set to 42.5%, even hoped to reach 45% following individual agreements by Member States. The 2023 Directive further insists on strengthening and enabling faster permission of new RES projects, such as turbines and solar panels, with increasingly simpler and faster administrative procedures, while numerous sectoral targets include a 42% share of hydrogen from RESs in total industrial hydrogen consumption by 2030 and a 60% target for 2035. In other words, in the transport sector, targets have been set to achieve a 29% share of RESs in transport by 2030 (or a 14.5% reduction in greenhouse gases through biofuels and other renewable fuels) [22].

Due to the aforementioned factors, we followed various indicators that are associated with the mentioned decrees, such as

- the energy rate from renewables in the transport sector;
- the energy rate from renewables in the heating and cooling sector;
- the rate of renewables' use within the total EU energy mix.

4. Results

Through an examination of the overall contribution of the energy generated from renewable sources in EU nations between 2004 and 2022, we reached the following conclu-

sions [20]. Most countries registered an increased rate of renewables use in the aforementioned period. For example, Denmark (DK) increased this rate from 14.8% in 2004 to 41.6% in 2022 and Sweden (SE) from 38.4% to 66.0%. Iceland (IS) and Norway (NO) have the highest share of renewable energy sources, with values of 85.8% and 75.8% in 2022, which indicates the strong dependence of these countries on renewable energy sources (Figure 1).

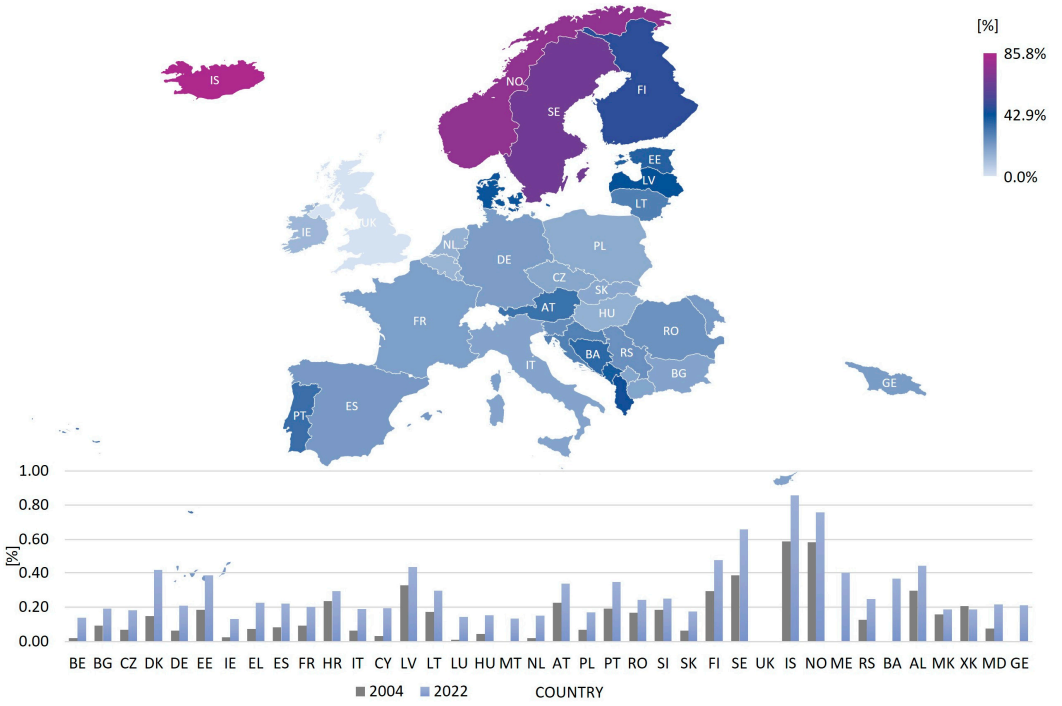

Figure 1. Total EU rates RES energy in 2004 and 2022 (%). Source: own processing according to Eurostat.

The following bar graph depicts the total share of energy obtained from renewable sources in the EU during 2004 and 2022. The map graph shows the total share of energy from renewable sources in the EU in 2022; this shows all energy from renewable sources. Some countries, such as Luxembourg (LU), Hungary (HU), and The Netherlands (NL), had relatively low initial percentage shares in 2004 but have also shown an increase in their shares as of 2022, in accordance with Directive 2009/28/EC of 2020 and Directive (EU) 2018/2001 from 2021. They outline the objective of increasing the contribution of renewable energy sources in the EU to 32% by 2030, while simultaneously stressing the need to improve energy efficiency and augment the RES share in transport to no less than 14%.

Evaluation of the various renewables used for electricity generation from 2004 to 2022 reveals that wind energy has experienced the most substantial increase, consistently gaining a larger portion of the renewable energy mix each year. Solar energy has seen an increasing trend, especially after 2010, which may be due to the decreasing cost of solar panels and improved technology. Hydropower, although still a significant part of renewable energy sources, is growing more slowly than other types, likely due to restrictions on new hydropower projects in Europe. The share of solid biofuels also increased, but they contribute relatively less than other sources (Figure 2).

At the beginning of the analyzed period, the total share of electricity produced from renewables was 15.87%. Figure 3 shows the structure of renewables use.

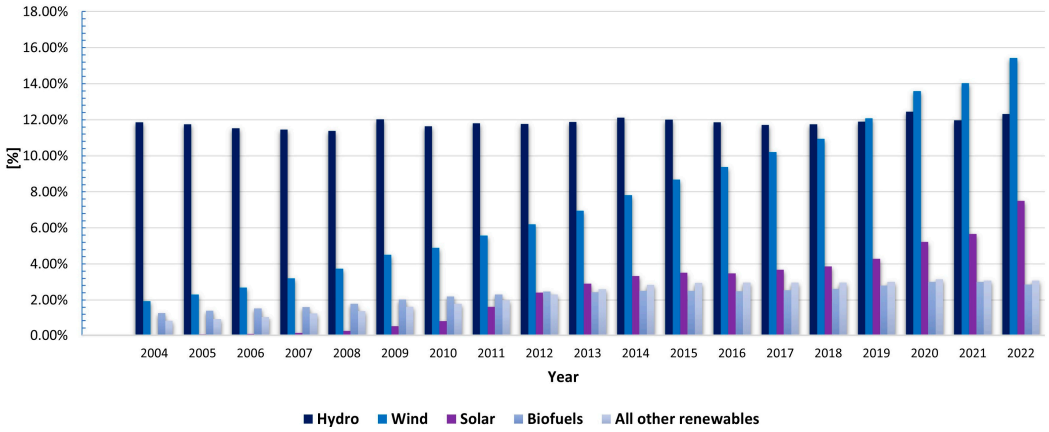

Figure 2. Development of chosen RES rate of electric energy produced in the EU. Source: own processing according to Eurostat.

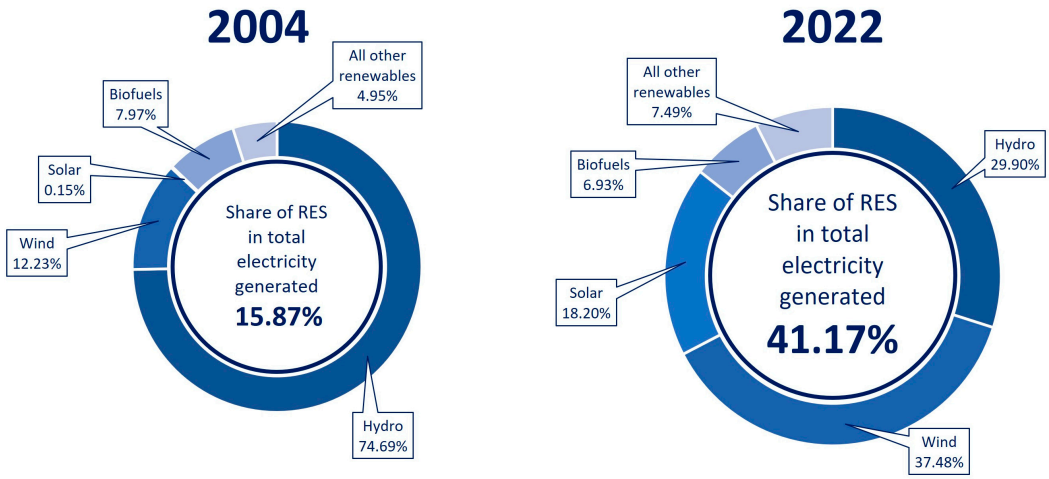

Figure 3. RES rate of total electric energy produced and the rate of various RESs within total electric energy produced from RESs in 2004 and 2022. Source: own processing according to Eurostat.

- The largest share was water energy (water energy)—74.69%.
- Wind energy accounted for 12.23%.
- Solid biofuels made up 7.97%.
- All other renewable energy sources made up 4.95%.
- Solar energy had the smallest share, of 0.15%.

By 2022, the total share of electricity produced by renewable energy sources increased to 41.17%. Compared to 2004, there has been a significant change in the structure of individual types of RES.

- The share of wind energy increased to 37.48%.
- Hydropower dropped to 29.90% but remains a significant source of renewable energy.
- Solar energy increased significantly to 18.20%.
- Solid biofuels now represent 6.93%.
- All other renewable energy sources decreased slightly to 7.49%.

The results show an important increase in renewables use in the past 18 years. This increase was recorded mostly in solar and wind energy, driven by technological advancements, increased efficiency, and political impetus for the EU to transition to more sustainable energy options.

RES use in chosen sectors

In response to the previous research, we examined rate of renewables use in the transport sector in EU countries in 2004–2022. In most countries, there have been changes in the use of energy from renewable sources in transport. Some countries, such as Belgium (BE), saw a significant increase from 0.6% in 2004 to 10.4% in 2022. At the same time, Sweden (SE), for example, increased its share from 6.3% to 29.2%, thereby showing one of the largest increases in the list (Figure 4). For the United Kingdom (UK), Iceland (IS), and Kosovo (XK), the figures for both years are 0.0%, which might indicate zero or negligible use of renewable energy in transport or missing data. The graph generally reflects the countries' efforts to implement these EU directives, which decreed an increase in the renewables rate, especially in the transport sector, which is an important aspect of the fight against climate change.

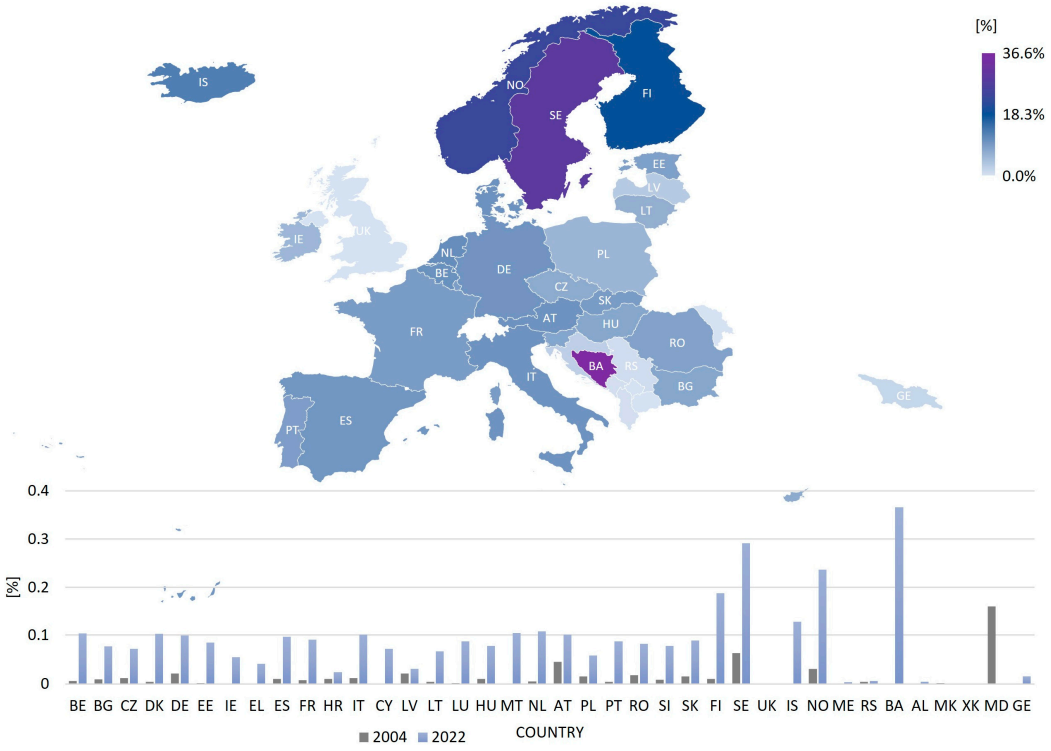

Figure 4. Rate of energy from RESs in transport in the EU in 2004 and 2022 (%). Source: Own processing according to Eurostat.

The analysis of the electricity production sector indicates a notable rise in the adoption of renewable energy sources across many countries from 2004 to 2022 (see Figure 5). The highest renewables rate was registered in Iceland (IS) and Norway (NO), where the share reached 93.1% more than 100%. This is probably due to the export of electricity. Albania (AL) showed a very high share of renewable energy use that exceeded 100% in 2022, likely indicating the significant use of hydropower. Denmark (DK) also showed an impressive increase in the use of renewable energy sources, increasing its share between 2004 and 2022 from 23.8% to 77.2%. Germany (DE) and Spain (ES) also recorded a significant increase, reaching 47.6% and 50.9%. Belgium (BE) registered a significant increase in the renewables rate as well, mainly from 1.7% to 29.1%.

The data indicate that European nations are enhancing their initiatives to boost the utilization of renewable energy, which is essential for meeting the EU's goals to decrease GHG emissions and to achieve a sustainable energy system.

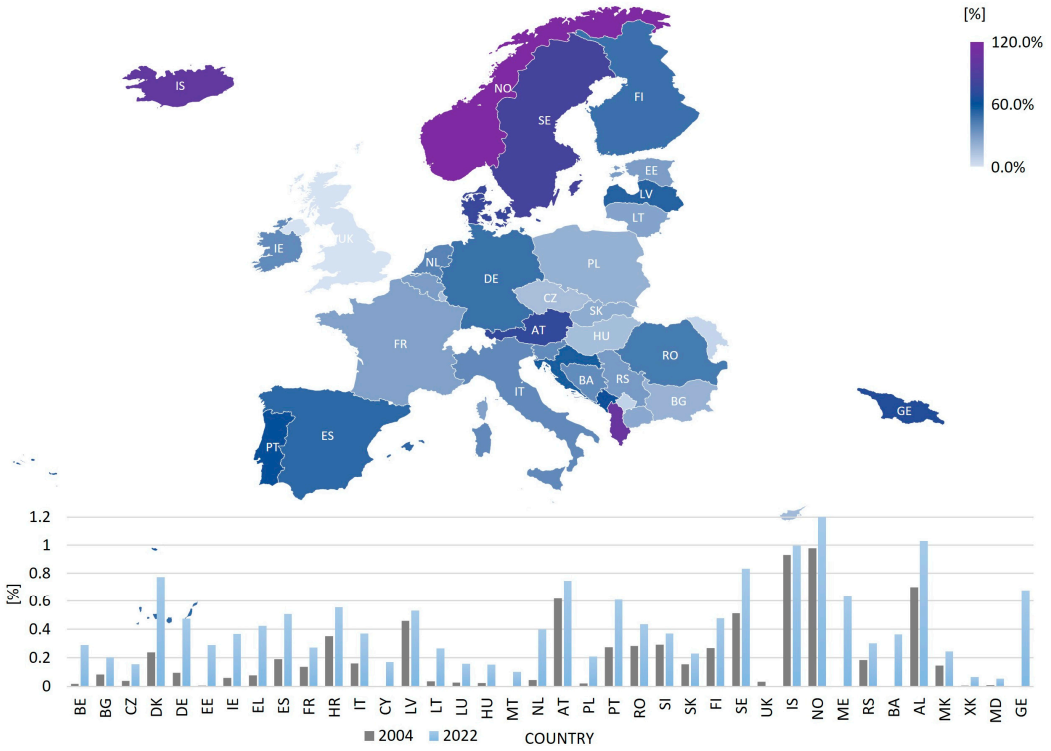

Figure 5. Rate of RES energy within gross electric energy consumption in the EU in 2004 and 2022 (%). Source: own processing according to Eurostat.

The heating and cooling sector, like the previously analyzed areas, saw significant changes in the shares of RES use (Figure 6). Estonia (EE) showed an impressive increase from 33.4% to 65.4%, being one of the highest shares. Denmark (DK) saw a significant increase from 20.5% to over 50.1%. Bulgaria (BG) reported an increase from 14.1% to 31.7%. Latvia (LV) and Lithuania (LT) maintained a high share of renewables with values above 50% in 2022. Germany (DE) saw a slight increase from 7.2% to 17.5%. Belgium (BE) increased its share of renewable energy sources from 2.9% in 2004 to 10.4% in 2022. Albania (AL), on the other hand, underwent a decrease in the share of RESs from 33.1% to 22.1%, which is not in alignment with most other countries in this table. Kosovo (XK) showed a slight decrease from 51.9% to 47.0%. In general, such data point to an increasing trend in renewables use in the heating and cooling sectors.

Comparing the sectors allows us to state that the renewables rate has increased over the years across all sectors (Figure 7).The year-on-year increase in the use of energy from renewable sources in the electricity, transport, and heating or cooling sectors has varied depending on the pace of technology development in the respective areas.

In 2020, the primary industry witnessed growth, hitting an unprecedented level of 9.74%. Along with 2011 and 2022, wind and solar energy contributed obviously to the growth of the sector in 2020. Only in 2021 did the growth reach slightly lower values (+0.91%), which can also be attributed to restrictions placed on the market.

The transport sector started with a very low share of RESs, with the highest increase occurring in 2008 (+42.91%) and the largest decrease in 2011 (−25.09%). In 2020, there was the most significant increase in subsequent years (16.48%), but the overall increase remained inconsistent.

The heating and cooling sector began consistent growth, led by a 12.19% expansion in 2007, which was related to heat pumps and biomass technologies. In 2022, there was an increase of 7.92% compared to the previous year, indicating continued development in this regard.

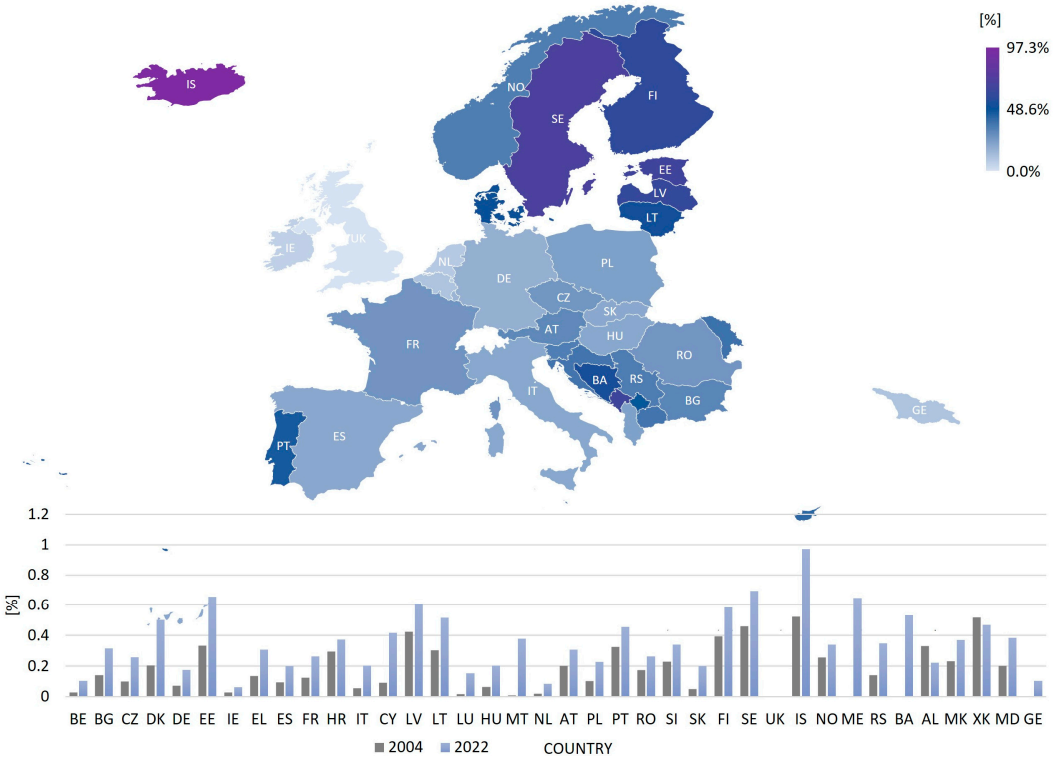

Figure 6. Rate of RES energy in the cooling and heating sectors in the EU in 2004 and 2022 (%). Source: own processing according to Eurostat.

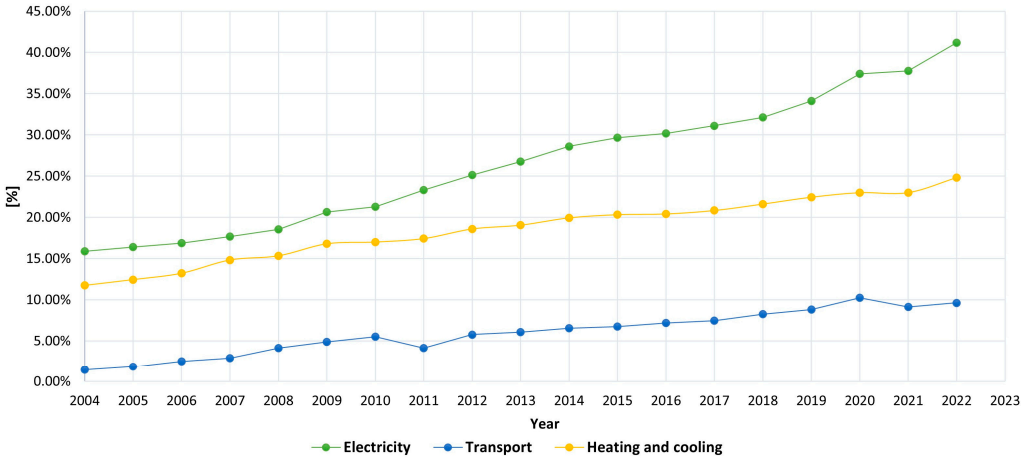

Figure 7. Development of the RES rate in various sectors in the EU. Source: own processing according to Eurostat.

Overall, electricity and heating dominate as the leading sectors in terms of results achieved, while transport still lags behind.

In 2022, there was a significant difference recorded in RES use between individual countries and economies. Iceland produced the highest volume of electricity from renewable sources per capita, at 51,470.50 kWh, while the EU average was only 2573.99 kWh per capita. Renewables have also achieved significant inroads in the heating and cooling sector. Finland recorded an overall high value of energy use from RESs in this sector (27,949.36 kWh per person).

Renewable energy sources in the transport industry varied considerably from country to country. Many other nations, such as Serbia (27.12 kWh per person) and Greece (230.53 kWh per person), recorded much lower levels of RES consumption in transport.

In comparison, Sweden (2388.62 kWh per person) and Luxembourg (2481.02 kWh per person) reached the highest values. The average energy consumption in the European Union was 676.06 kWh per person. Countries such as Iceland (1408.56 kWh) and Norway (2156.38 kWh) contributed significantly to this increase. Some regions, such as Kosovo and Albania, do not use RESs in transport, despite progress in many other countries. This shows the need for further funding and technological progress in this area.

Figure 8 illustrates RES use in the electricity, heating and cooling, and transport sectors, where we can see energy use per person in 2022. Figure 9 illustrates the total energy from RESs per person in 2022.

At the top of the overall list of countries using RESs in all sectors are Iceland (86,957.03 kWh per person) and Norway (41,685.33 kWh per person), which points to the significant contribution of these countries to increasing the share of RESs. In contrast, other countries including Kosovo (3898.48 kWh per person) and Albania (4116.47 kWh per person) continued to place in the lowest ranks, pointing to the need for greater investment and technological progress in these areas. Heating and cooling have maintained stable development, with the leaders in this area being Finland (36,749.64 kWh per person) and Sweden (30,869.00 kWh per person).

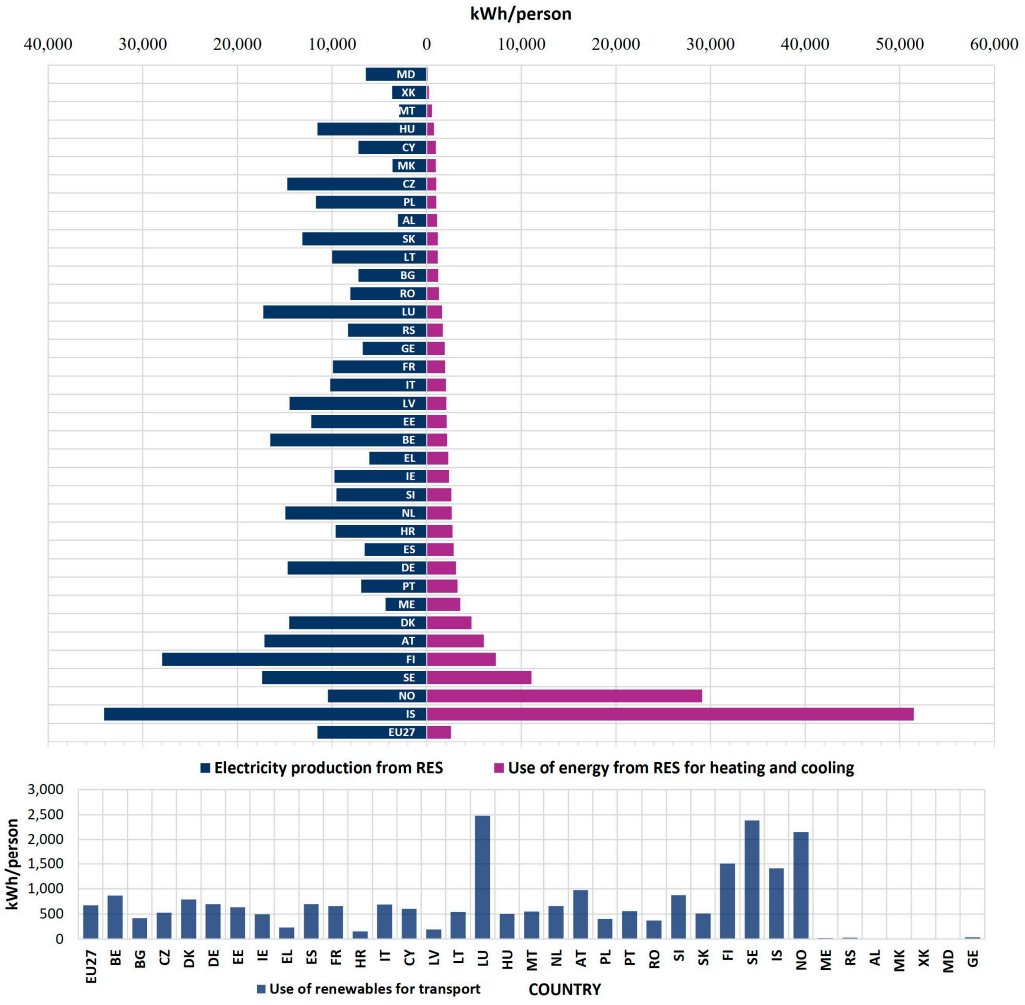

Figure 8. RES energy use in different sectors in EU Member States per person, 2022. Source: own processing according to Eurostat (electricity, heating and cooling, transport).

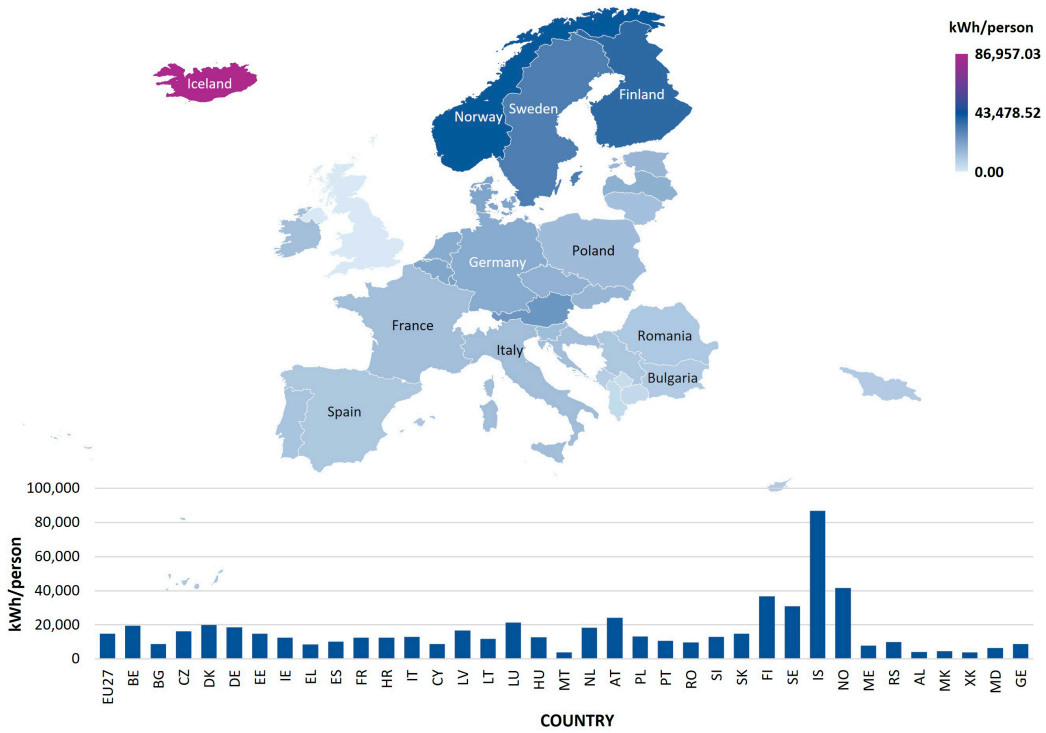

Figure 9. Use of total energy from RESs per person in 2022. Source: own processing according to Eurostat.

5. Discussion

The previous analyses led to the following conclusions.

Over the last two decades, the use of renewable energy sources (RESs) in the European Union has increased significantly and steadily. This confirms the findings of Jalowiec and Wojtaszek [23]. However, they noted that investors in RESs are currently primarily interested in investing in renewable energy in highly developed countries.

This applies to various sectors including electricity, transport, and heating/cooling. The transport sector has shown the slowest progress in increasing the share of RES, which may be a reflection of larger technical and infrastructural problems. The poor quality and insufficient capacity of the electricity grid in most EU countries primarily hinder the slow development of RESs in transport [24]. Paradoxically, developed countries, with relatively well-maintained electricity grids, invest more in grid modernization than post-communist countries. Another problem is the non-existent hydrogen distribution network and hydrogen stations.

In the area of transport, Lindstad et al. emphasized the following priorities up to 2050 [25]:

- Replacing coal-fired electricity production with new renewable energy sources, which can nearly decarbonize the electricity grid;
- Gradually electrifying road transport;
- Continuing the use of fossil fuels in shipping and aviation.

According to Matuszewska-Janica et al., EU Member States meet energy policy principles by increasing the renewables rate in electricity production and by diversifying the types of renewables used [26].

As for the renewables rate in the heating and cooling sector, increasing attention is currently being paid to the integration of phase change materials (PCMs)—such as underground energy storage systems or phase-change materials—with solar collector systems, photovoltaic systems, or thermoelectric installations [27].

In the analyzed period, the structure of renewables changed as well. The rate of hydropower decreased slightly in favor of rapid growth in solar and wind energy, reflecting the technological advancements in and declining costs of these technologies. Ellabban et al. have highlighted the greater proportion of renewables in electronics and smart grid technologies [28].

The share of renewable energy sources in the overall energy mix of the EU has increased across all examined sectors, most notably in the electricity generation sector, which demonstrates the effectiveness of EU policy in this area. Additionally, we should consider how the share of RES in the energy mix affects social welfare. In this regard, Kwangwon et al. found that a 10% increase in renewables in the energy mix decreases social welfare by 0.753% in the long term [29]. This negative effect is caused by the negative impact of reduced cost-efficiency, which positively impacts reduced climate damage.

These results indicate a significant increase in the use of renewable energy sources over the past 18 years. The outcomes of RES use in the heating and cooling sector are similar to those reported by Wietschel et al. [30]. These authors found that producing electricity primarily from RES is essential for harnessing the GHG emission reduction potential of sector-coupling technologies. However, in the long term, the timely entry of sector-coupling technologies into the market is necessary. Sector-coupling technologies can enhance power system flexibility, which is relevant for systems with high rates of various renewables. We must note that the potential flexibility of these technologies is different [30].

In spite of the positive development of RES use, there is still a need to address barriers. As stated by Gajdzik et al., administrative barriers significantly hinder the development of renewables, particularly in less developed EU countries [31]. On the other hand, grid-related obstacles are ordinary in Southern–Central Europe.

Moreover, tracking renewable energy use in individual sectors helps countries move towards sustainability and meet climate goals more effectively [32]. The use of new renewables and the maintenance of investments in older RESs must be part of each state's strategy to make its electricity grid less vulnerable to climate change.

Companies and sectors investing in sustainable solutions, including RES use, can gain a competitive advantage and create new jobs in the green economy [33]. Sustainability and green energy (GE) are connected to the common goal of promoting environmental stability, economic prosperity, and social equity, with green energy related to RES use.

Different sectors have specific regulations and targets, such as obligations to achieve certain levels of emission reduction. To meet these goals, it is necessary to monitor the share of renewable energies and analyze their efficiency so that sectors can adapt to future requirements. Recent EU energy policy aims to mainstream RE prosumers (i.e., communities, using renewables, energetic communities of citizens, and common acts of renewables self-consumers) in each member state [34]. The current EU legal framework represents a clear opportunity for collective prosumers.

Understanding the extent of RES use is crucial for various groups and institutions, including the following.

- Government institutions and policy decision makers: this information can inform the development of energy and climate policies, legislation, and emission reduction goals.
- Individual sectors; their transition to green energy requires support.
- Regulatory organizations and environmental agencies: these organizations must address energy limits and monitor sustainability, especially when experts use RES data to create dynamic guidelines and regulations.
- Industrial sectors and individual companies: Knowledge of RES use is essential for compliance with regulations and realizing economic benefits such as cost savings, process optimization, and enhanced competitiveness.

6. Conclusions

The results of the analysis demonstrate the EU's commitment to a cleaner energy transition and progress towards the goals of reducing dependence on fossil fuels and combating climate change. This paper is limited to the use of RESs in the transport, cooling and heating, and electricity production sectors. In all these sectors, the Nordic countries—(in alphabetical order) Denmark, Finland, Iceland, Norway and Sweden—have long stood out significantly. Among the Central European countries, Austria and Germany stand out. An interesting finding is the significant growth of the so-called post-communist countries such as Estonia, Latvia, Lithuania but also of the "newcomers" such as Bosnia and Herzegovina and Albania.

These findings prove that RESs can be successfully implemented in all countries regardless of geographical location or date of entry into the EU.

Future studies could therefore explore the application of renewable energy sources across various sectors, such as agriculture, electric mobility, the green economy, and technological innovation. It would also be valuable to compare the economic development of RES usage with its energy and ecological potential over time, as RES usage evolves. This comparison could be a focus of the next study by our research team.

One of the focuses of the paper was the thesis that publishing the results of the development of RES implementation in individual industrial sectors in EU countries proportionally supports a further increase in interest in RESs as well as the real use of RES in practice. Research results on the rate of RES use in specific sectors may be valuable for a wide range of users.

Researchers can use this information for analysis, supporting climate change modeling, the development of new technologies, and improved energy efficiency predictions. Investors and banks are increasingly motivated to invest in sustainable projects and therefore need information on the use of renewable energy sources across various industries. Based on these data, they can better assess the risks and returns of green investments. Information on renewable energy use is also important for the public, who want to use RESs in their homes. The media disseminates these data, thereby raising awareness and increasing pressure on both the private sector and public administration.

In summary, based on the survey, we can conclude that over the monitored period of 2004–2022, the fastest increase in the implementation of RES was recorded in the electricity generation sector (more than 25%); the heating and cooling sector increased by more than 13%, and in transport, the share of RES increased by more than 8%.

Awareness of how frequently renewable energy is used enables all stakeholders to make well-informed decisions that contribute to a sustainable future and efforts to mitigate climate change.

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