

ANALYSIS OF THE ENERGY MIX IN POLAND AND THE EUROPEAN UNION IN TERMS OF RENEWABLE ENERGY PROSPECTS

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Purpose: The article aimed to understand the structure of the energy mix in EU countries, particularly in comparison with Poland, from 1990-2022.

Design/methodology/approach: The research was conducted on data from 27 EU countries between 1990 and 2022 using statistical methods with particular emphasis on analysis of the dynamics of phenomena and clustering.

Findings: Studies have confirmed a substantial increase in the share of renewable energy sources (RES) in the energy mix of the EU countries. A considerable increase was recorded in wind and solar energies. However, solid fuels still are in use in EU countries, particularly in countries whose economies are based on coal, including Poland.

Originality/value: The article's value is to view the development energy mix in Poland and the EU from a multidimensional analysis conducted in two separate time units. It allowed conclusions about the development of RES in Poland and the EU to be drawn.

Keywords: energy mix, renewable energy sources, electricity and derived heat production. cluster analysis.

Category of the paper: research paper.

1. Introduction

In recent years, responsibility for environmental protection has gained value and has become unquestionable. Worldwide changes, particularly concerning environmental issues, have forced, among other things, an adjustment in how energy sources should be used. Trends towards an increasing share of renewable energy sources (RES) in energy production have resulted in many separate and joint regulations in individual countries.

The evolution of the EU's emissions reduction policy dates back to the 1990s (Skjærseth, 2021; Jorge-Vazquez et al., 2024). One of the first climate policy instruments in the European Union was the mandatory EU Emissions Trading Scheme (2003). The main issues addressed were climate change, energy security and economic growth. The Lisbon Strategy (2000-2010) was also in place independently. In 2007, a target was set (compared to 1990 levels):

a 20% reduction in greenhouse gas emissions, a 20% increase in EU energy from renewable sources, and a 20% improvement in energy efficiency up to 2020. In October 2014, the Paris Agreement adopted a climate and energy policy framework for 2030, including a new national greenhouse gas reduction target of at least 40% compared to 1990 and a 27% increase in renewable energy consumption. Several regulations on emissions and climate change followed this. In fact, between 1990 and 2016, greenhouse gas emissions in the EU fell by more than 20%. Finally, the European Green Deal was launched in December 2019 (Skjærseth, 2021). And then, on 14 July 2021, the European Commission announced a legislative package on climate and energy - Fit for 55. The package is a set of relevant legislative proposals, subordinated to the EU's main climate target of reducing greenhouse gas emissions compared to 1990 levels by at least 55% by 2030 and making the EU climate-neutral by 2050 ("Fit for 55" 2023; *Regulation (EU) 2021/1119*, 2021). Essential aspects included minimising final energy consumption while increasing the share of renewable energy sources in the overall energy mix. As a result, EU members have been developing new legislation to accomplish.

In 2021, Poland issued a document entitled "Energy Policy of Poland until 2040" (PEP2040). The directions of PEP2040 include the optimal use of indigenous energy resources, the development of energy markets, the implementation of nuclear power, the development of renewable energy sources, and the improvement of the economy's energy efficiency (PEP2040, 2021). Also, after Russia's aggression in Ukraine, the Polish Minister of Climate and Environment issued assumptions for the PEP2040 update, in which the need for Poland's energy self-sufficiency further emphasised the importance of RES in diversifying the energy mix. According to the document, just about half of the electricity generated should come from renewable sources by 2040 (Ministry of Climate and Environment, 2022).

Many studies show that there has been a noticeable increase in the share of energy from renewable sources in recent years in European countries (Olczak, Matuszewska, Kryzia, 2020; Brodny, Tutak, Bindzár, 2021; Sobczyk, Sobczyk, 2021; Bórawski et al., 2022; Jonek-Kowalska, Kurdelski, 2022; Mularczyk, Zdonek, 2022; Wolniak, Skotnicka-Zasadzień, 2022, 2023; Zdonek et al., 2022; Brodny, Tutak, 2023; Jonek-Kowalska, 2023; Mularczyk, 2023; Simionescu, Rădulescu, Cifuentes-Faura, 2023; Hassan et al., 2024; Hysa, Mularczyk, 2024; Stec et al., 2024) as well as all over the world (Azarpour et al., 2022; Lau et al., 2022; Qaiser, 2022; Triguero-Ruiz, Avila-Cano, Trujillo Aranda, 2023; Yolcan, 2023, 2023; Hassan et al., 2024; Tiwari et al., 2024; Zhang, Wang, Liu, 2024). Nonetheless, although the energy mix has diversified significantly in recent years, the use of fossil fuels in the EU is still a significant source of direct CO₂ emissions (Paraschiv, Paraschiv, 2020).

Research conducted by (Miciuła et al., 2020) confirms that the demand for energy resources among EU countries is vast. These countries consume 16% of the energy produced in the world and primarily have to import it. Therefore, considering the peculiarities of each country's energy mix, there is a need to measure and ensure the sustainable development of all EU members and energy security based on the rational and efficient use of energy resources.

Increasing the share of renewable energy sources in the energy mix also contributes to energy security by reducing dependence on imported energy carriers (Sobczyk, Sobczyk, 2021). In particular, in the fact of the Russian conflict in Ukraine, in the face of the energy crisis (caused by rising electricity prices), energy conservation, security and reducing dependence on imports of fossil fuels, especially coal, and an accelerated transition to nuclear and renewable energy, have become a necessity for EU countries (Brodny, Tutak, 2023; Hille, 2023; Koval et al., 2023; Kartal et al., 2024).

Some EU countries have made significant progress in the energy transition (e.g., Sweden and Denmark). While others face more significant energy transition challenges related to the decarbonisation of their energy sector (e.g., Poland) (Jonek-Kowalska, 2022; Kaczmarek, Kolegowicz, Szymła, 2022; Koval et al., 2023; Jonek-Kowalska, Grebski, 2024; Jonek-Kowalska, Rupacz, 2024; Jorge-Vazquez et al., 2024; Manowska et al., 2024). However, the share of coal in Poland's energy mix decreased primarily after 2015 compared to previous years (Rybak et al., 2024). And there has been an unquestionable rise in the use of RES in our country in the last decade (Olczak, Matuszewska, Kryzia, 2020; Kulpa et al., 2022; Mularczyk, Zdonek, 2022; Wolniak, Skotnicka-Zasadzień, 2022, 2023; Zdonek et al., 2022; Jonek-Kowalska, 2023; Mularczyk, 2023; Hysa, Mularczyk, 2024; Jonek-Kowalska, Rupacz, 2024; Świdzińska, 2024).

According to the literature analysis, no studies were reported comprehensively on the structure of the energy mix and the structure of renewable energy sources used for energy production in Poland against the background of the European Union countries for the entire period since the beginning of the foundation of the EU in 1990. Therefore, the article aims to learn about the structure of the energy mix in EU countries, particularly in comparison with Poland, from 1990-2022. Three main research questions were posed, each of which was further developed regarding Poland to achieve this aim:

RQ1: How did the share of individual resources in electricity and heat production in the EU change between 1990 and 2022?

RQ1a: How did the share of individual resources in electricity and heat production in Poland change between 1990 and 2022?

RQ2: How has the structure of renewable energy sources in the energy mix in the EU changed from 1990 to 2022?

RQ2a: How has the structure of renewable energy sources in the energy mix in Poland changed from 1990 to 2022?

RQ3: What groups could EU countries be divided into regarding the energy mix in 1990 and 2022?

RQ3a: How did Poland compare to other EU countries regarding energy mix in 1990 and 2022?

2. Materials and Methods

The data was collected from the open data platform Eurostat (*Eurostat*, 2024). It was concerned for electricity and derived heat production by fuel type in European Union countries from 1990 to 2022, assessed in thousand tonnes of oil equivalent (ktoe). Initially, data was assembled by distinguishing fuel types: solid fossil fuels, oil and petroleum products, natural gas, nuclear heat, and renewables with biofuels. Then, the structure of renewables was analysed. It included hydro, geothermal, wind, solar, primary solid biofuels, biogases, and renewable municipal waste. Statistical methods with particular emphasis on analysis of the dynamics of phenomena and clustering were used. Calculations were performed in a spreadsheet and the R Studio environment.

3. Results

The research results were presented in the following order: firstly, the general structure of electricity sources and derived heat in the European Union and Poland separately, and secondly, more accurate results concerning renewable energy sources in the same scheme. Finally, in the third part of this chapter, all 27 countries currently members of the EU were clustered for the beginning and end of the period under review two times: in terms of energy mix and renewable energy sources structure.

3.1. The energy in the European Union and Poland

To answer the first research question – RQ1 (How did the share of individual resources in electricity and heat production in the EU change between 1990 and 2022), the European Union's energy structure was initially analysed. Figure 1 presents a column chart showing the change in the structure of energy and derived heat sources between 1990 and 2022 combined in all 27 countries currently members of the European Union.

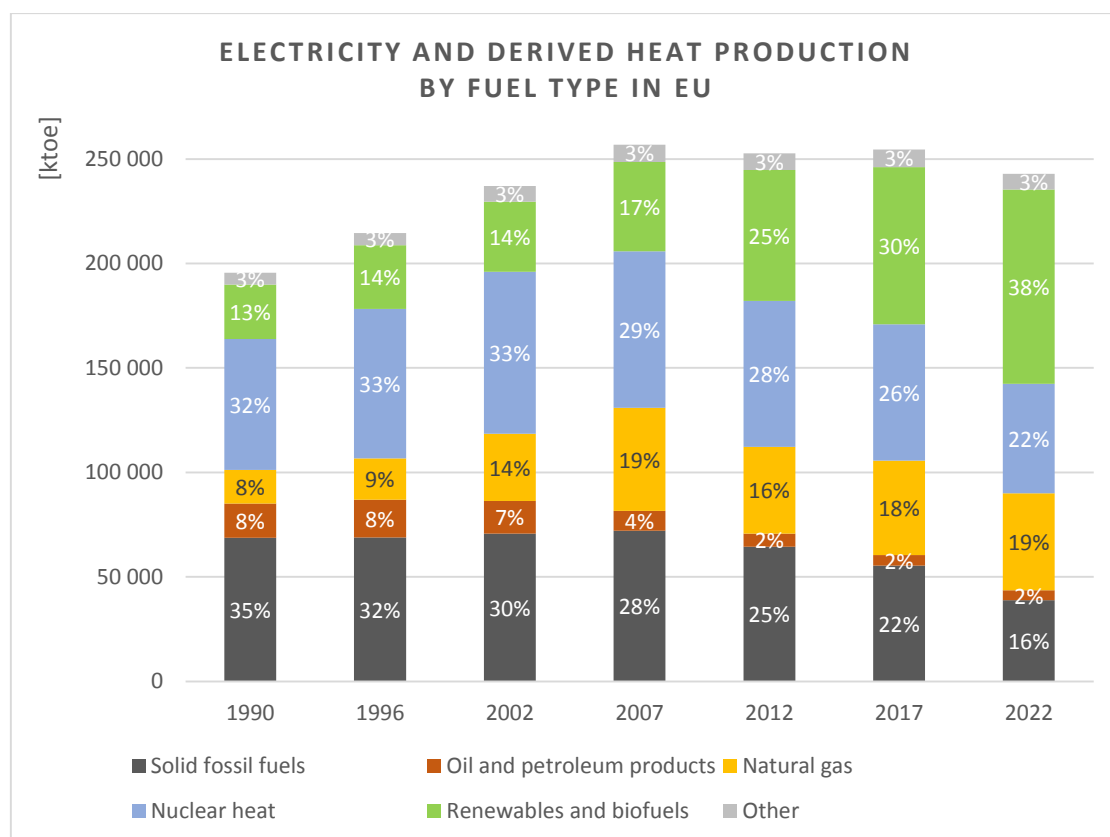


Figure 1. Electricity and derived heat production by fuel type in the European Union.

Source: own calculations based on data from (Eurostat, 2024).

Table 1, in turn, displays calculations of the dynamics of change of these shares in 2022 compared to 1990 (and 2007 for comparison) in total in the countries studied.

Table 1

The change in EU production and share of electricity and derived heat by fuel type

Source	1990		2022		Increase/decrease in 2022			
	Total [ktoe]	Share of total	Total [ktoe]	Share of total	compared to 1990		compared to 2007	
					Total	Share	Total	Share
Solid fossil fuels	68 792.43	35%	38 799.54	16%	-44%	-55%	-46%	-43%
Oil and petroleum products	16 296.05	8%	4 793.07	2%	-73%	-76%	-49%	-46%
Natural gas	16 127.52	8%	46 507.02	19%	135%	107%	-6%	-0,3%
Nuclear heat	62 692.52	32%	52 386.54	22%	-16%	-33%	-30%	-26%
Renewables and biofuels	25 958.61	13%	92 844.18	38%	258%	188%	118%	130%

Source: own calculations based on data from (Eurostat, 2024).

The total energy and derived heat production was in 1990 the level of 195,637 and in 2022: 242,843 [ktoe]. It represents an overall increase of 24%. However, a graph shows that after an initial apparent growth trend, it breaks down around 2007. It remains more stable or slightly declining instead. In 2007, energy production reached 256,903 [ktoe]. In these conditions, there was a visible decrease in fossil fuel share of about half (54%), from 35% to 16%. There were also decreases in shares of oil and petroleum products (76%, from 8% to 2%) and nuclear heat (33%: from 32% to 22%). In contrast, the share of natural gas increased from 18%

over the period under review, reaching a maximum around 2007 (19%; 49,325 [ktoe]), with the share in 2022 being 107% higher than in 1990. However, the share of renewable energy sources showed the most intense growth. It changed from 13% to 38%, representing a 188% share growth, with a total product amount increase of 258% (from 25,959 to 92,844 [ktoe]).

In turn, a similar analysis was conducted for Poland to compare and answer research question RQ1a (How did the share of individual resources in electricity and heat production in Poland between 1990 and 2022). Figure 2 presents a graph showing the structures of energy sources and derived heat between 1990 and 2022 in Poland. Nuclear heat was not included at this time because it did not exist in Poland during the analysed period.

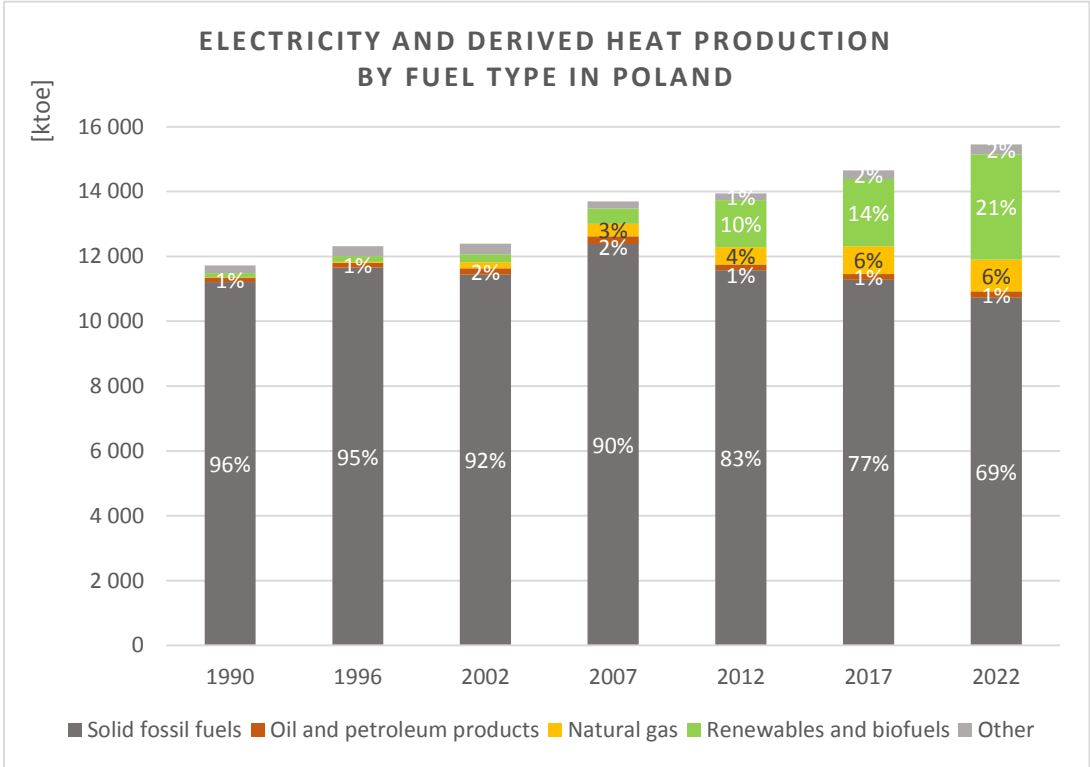


Figure 2. Electricity and derived heat production by fuel type in Poland.

Source: own calculations based on data from (Eurostat, 2024).

Analogously, Table 2 shows calculations of the dynamics of change in these shares in 2022 compared to 1990 and 2007 in Poland.

Table 2*The change in Poland's production and share of electricity and derived heat by fuel type*

Source	1990		2022		Increase/decrease in 2022			
	Total [ktoe]	Share of total	Total [ktoe]	Share of total	compared to 1990		compared to 2007	
					Total	Share	Total	Share
Solid fossil fuels	11 209.03	96%	10 724.61	69%	-4%	-27%	-13%	-23%
Oil and petroleum products	135.00	1.2%	202.29	1,3%	33%	6%	-16%	-25%
Natural gas	10.75	0.1%	976.34	6,3%	3415%	2700%	153%	125%
Renewables and biofuels	128.51	1%	3 240.63	21%	2422%	1812%	594%	515%

Source: own calculations based on data from (Eurostat, 2024).

As for Poland, a significant change could be observed in how electricity and derived heat were produced. While 96% of the source of this energy was solid fuels, by 2022, almost a third of the power already came from other sources. Although the amount of energy from fossil fuels only slightly dropped (from 11,209 to 10,725 ktoe, which stands for 4%), its share in the energy mix significantly decreased – by 27% (from 96% to 69%). Also, in 2022, corresponding to 1990, slight growth in oil and petroleum product usage could be noticed (6%). However, it is worth noticing that the usage of this source was even higher in 2007 and then dropped. A visible increase was noted in natural gas use. This source's share has been successfully developing from almost nothing (0.1%; nearly 11 [ktoe]) to 6.3% (976 [ktoe]), meaning a 2,700% growth. However, the most substantial improvement regarding renewables and biofuels during the analysed period was noticed. The energy production from these sources initially of about 129 [ktoe] in 1990 amounted to 3,241 [ktoe] in 2022, as its share grew from 1% to 21%. It stood for a 1,812% growth in share and 2,422% in total.

3.2. The energy from renewables in the European Union and Poland

As the most significant increases in Poland and the European Union have been from the perspective of renewable energy sources, a more in-depth analysis of this phenomenon was the next step. It was addressed by research questions RQ2 and RQ2a. First, to answer research question RQ2 (How has the structure of renewable energy sources in the energy mix in the EU changed from 1990 to 2022), the production of renewable electricity and derived heat in 27 European Union countries was analysed by isolating individual renewable energy sources. Figure 3 presents renewable energy production divided into seven sub-categories according to source: hydro, geothermal, wind, solar (it included both photovoltaics and solar-thermal), primary solid biofuels, biogases, and renewable municipal waste. Likewise, Table 3 shows the total values and shares of the analysed RES.

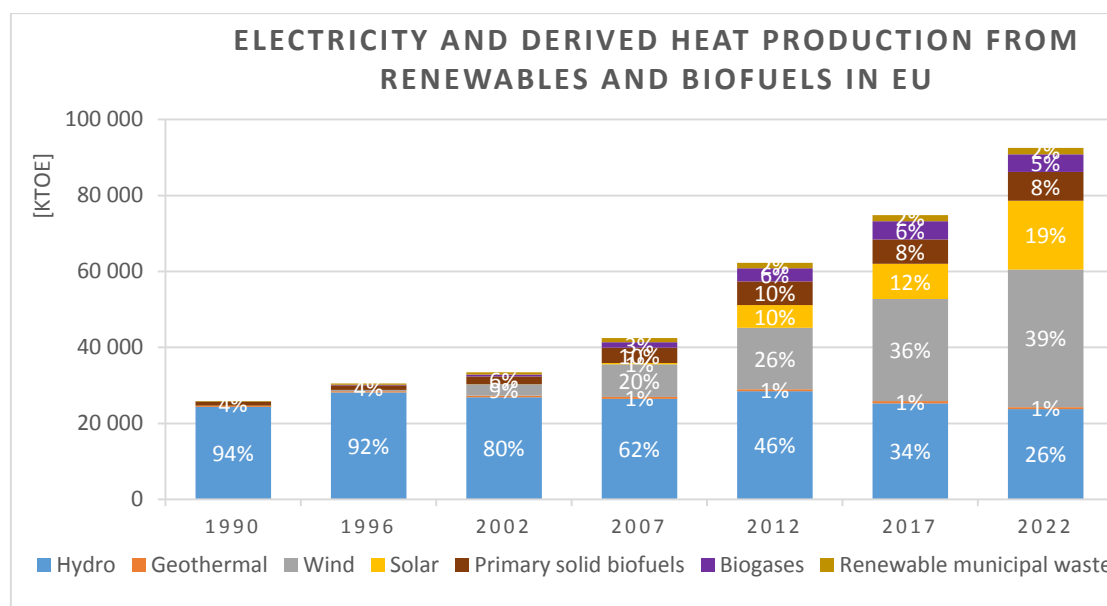


Figure 3. Electricity and derived heat production from renewables in the European Union.

Source: own calculations based on data from (Eurostat, 2024).

Table 3.

The change in EU production and share of electricity and derived heat from renewables

Source	1990		2022		Increase/decrease in 2022			
	Total [ktoe]	Share of total	Total [ktoe]	Share of total	compared to 1990		compared to 2012	
					Total	Share	Total	Share
Hydro	24 388.94	94%	23 752.14	26%	-3%	-73%	-17%	-44%
Geothermal	277.39	1.1%	552.69	0,6%	69%	-44%	10%	-25%
Wind	66.15	0.3%	36 226.74	39%	9,501%	3,059%	125%	52%
Solar	1.37	0.01%	18 078.18	19%	1,324,309%	370,196%	200%	102%
Primary solid biofuels	939.41	4%	7 569.62	8%	706%	125%	22%	-18%
Biogases	39.49	0.2%	4 669.88	5%	11,727%	3,207%	34%	-10%
Renewable municipal waste	202.67	1%	1 661.72	2%	720%	129%	16%	-22%

Source: own calculations based on data from (Eurostat, 2024).

The bar chart confirmed the increase in energy production from renewable energy sources. It changed from 25,959 to 92,844 [ktoe], which meant an increase of 258%. The primary energy renewable source in 1990 was water. At that time, hydropower covered 94% of RES production. But, in 2022, it already accounted for only 26%, which meant a 73% decrease in share. Nonetheless, this source showed some stability, as the total energy produced from it only dropped by 3%. Namely, in 1990, it was 24,389; in 2022, it was slightly less, 23,752 [ktoe]. Such a significant decline in share was caused by an even greater increase in the importance of RES in the overall energy mix. Similar conclusions could be drawn about geothermal energy, although its share was not as significant. Production from this source more than doubled in the period under review (69%: from 277 to 553 [ktoe]); however, when looking at its percentage share of total RES, it fell by as much as 44% (from 1.1% to 0.6%) and then has a marginal share of the total RES for now.

On the contrary, since the beginning of the 21st century, the unquestionable boom in the EU has been in wind power and, since around 2012, solar sources. Wind power increased from nearly 66 [Ktoe] in 1990 (which was about 0.3% of the share in renewables) up to 36 227 [ktoe] (39% of the share). It showed the most rapid growth among EU renewable sources, as seen in the chart above. However, solar sources have also been developing rapidly in the last decade. In 1990, the amount of energy from solar sources was only about 1.4 [ktoe], which accounted for almost nothing (approximately 0.01%); in 2022, the same source gave 18 078 [ktoe] instead (19% of the share). Compared only to 2012, by 2022, solar energy has increased by 102% in share and about 200% in total. Also, significant developments in such sources as primary solid biofuels, biogases, and renewable municipal waste can be seen. However, even in 2022, their share did not exceed 10%.

An equivalent analysis was conducted for Poland to compare results and answer research question RQ2a (How has the structure of renewable energy sources in the energy mix in Poland changed from 1990 to 2022). In Figure 4, the bar chart presents renewable energy production divided into six sub-categories according to source: hydro, wind, solar (photovoltaics and solar-thermal), primary solid biofuels, biogases, and renewable municipal waste. Geothermal was not applicable in Poland during the analysed period. Table 4 also shows the total values and shares of the analysed RES.

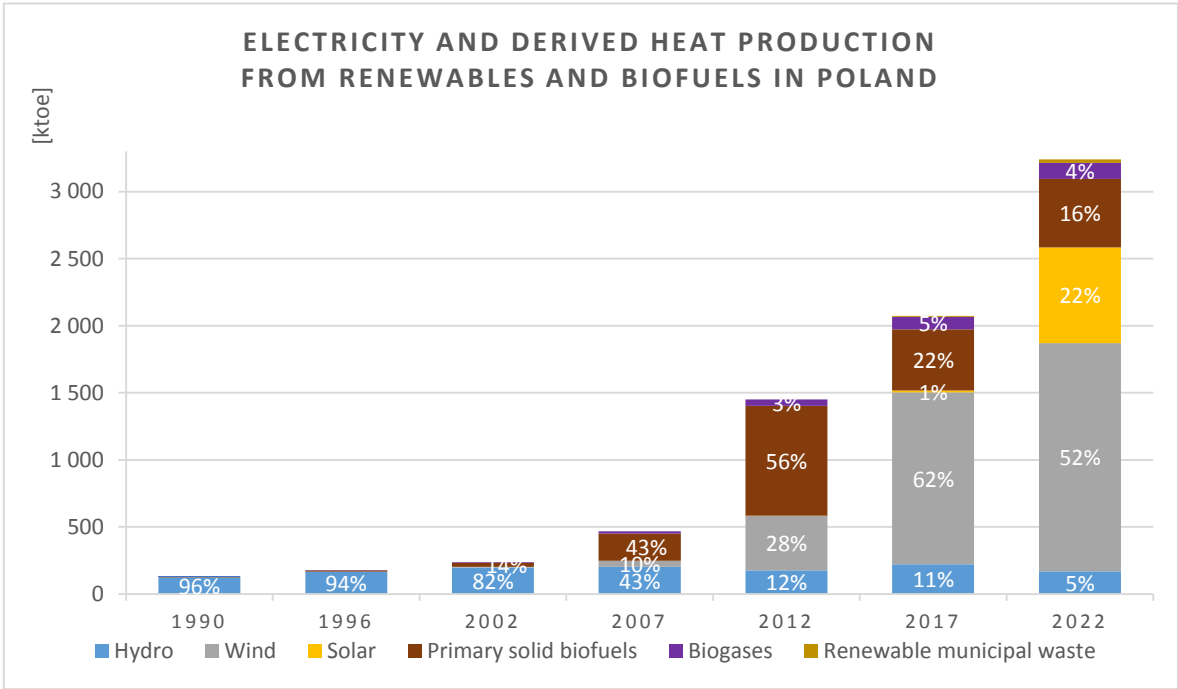


Figure 4. Electricity and derived heat production from renewables in Poland.

Source: own calculations based on data from (Eurostat, 2024).

Table 4

The change in Poland's production and share of electricity and derived heat from renewables

Source	1990		2022		Increase/decrease in 2022			
	Total [ktoe]	Share of total	Total [ktoe]	Share of total	compared to 1990		compared to 2012	
					Total	Share	Total	Share
Hydro	123.78	96%	169.23	5%	37%	-95%	-3%	-57%
Wind	-	-	1 700.73	52%	-	-	317%	87%
Solar	-	-	714.50	22%	-	-	728 985%	326 419%
Primary solid biofuels	4.73	4%	510.24	16%	10 690%	328%	-38%	-72%
Biogases	-	-	119.88	4%	-	-	147%	10%
Renewable municipal waste	-	-	25.94	1%	-	-	-	-

Source: own calculations based on data from (*Eurostat*, 2024).

Analysing Poland's energy mix, it appeared that renewable energy sources and their importance were discovered in the first or even second decade of the 21st century. It was undoubtedly related to the political and regime changes in the last decade of the 20th century. In 1990, only two renewable energy sources were visible: hydro and primary solid biofuels. Nevertheless, energy from water accounted for as much as 96% of the total RES used. Although hydro energy's share dropped significantly (to 5%), its production increased indeed (from 124 to 169 [ktoe], which indicated a 37% rise). Also, primary solid biofuels expanded from nearly 5 to above 510 [ktoe], representing a 16% share in 2022. In their place, wind had the largest share of RES in 2022 (52%), followed closely by solar sources (22%). Both of these sources were virtually non-existent in 1990. Additionally, in 2022, trace amounts (not exceeding 5%) of biogas and renewable municipal waste could be seen among RES.

3.3. Cluster analysis

European countries differ in many ways, such as geographical location, possession of natural resources, and economic status. These differences have an impact on the structure of the energy mix. Therefore, in the further part of the analysis, all EU countries were clustered to group those with similar characteristics. The purpose was to answer the last two research questions: RQ3 (What groups could EU countries be divided into regarding the energy mix in 1990 and 2022) and RQ3a (How did Poland compare to other EU countries regarding energy mix in 1990 and 2022).

Energy mix in 1990

Figure 5 presents the clustering result for all 27 countries currently belonging to the EU due to their structure of individual sources in the energy mix in 1990. The calculations were carried out for Euclidean distances using the Ward method.

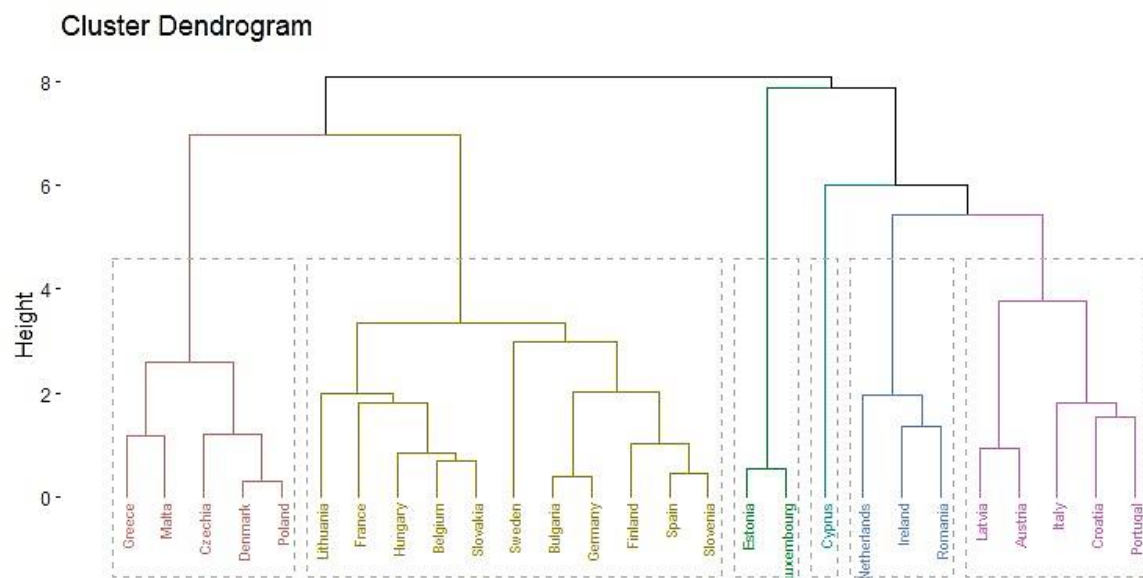


Figure 5. Results of Cluster Analysis for energy mix in 1990.

Source: own calculations.

It seemed best to divide the countries surveyed into six groups. The membership of each group is shown in Table 5.

Table 5.
Countries in each cluster for 1990

Cluster	Country
1	<u>Belgium</u> , Bulgaria, <u>Germany</u> , <u>Spain</u> , <u>France</u> , Lithuania, Hungary, Slovenia, Slovakia, Finland, Sweden
2	Czechia, <u>Denmark</u> , Greece, Malta, Poland
3	Estonia, <u>Luxembourg</u>
4	<u>Ireland</u> , <u>Netherlands</u> , Romania
5	Croatia, <u>Italy</u> , Latvia, Austria, <u>Portugal</u>
6	Cyprus

Note: the underlined countries were already members of the EU at that time.

Source: own calculations based on data from (Eurostat, 2024).

It can be noted that the grouping in 1990 did not depend on whether a given country was in the EU at that time. The rationale for this partition is shown in Table 6, which places the average shares of each type of source in each group.

Table 6.
The average share of individual energy sources in clusters for 1990

Cluster	1	2	3	4	5	6
Average production [ktoe]	11 976	4 488	798	4 322	5 347	170
<i>Solid fossil fuels</i>	26%	78%	0%	40%	13%	0%
<i>Natural gas</i>	7%	1%	4%	38%	15%	0%
<i>Oil and petroleum products</i>	5%	14%	5%	11%	24%	100%
<i>Renewables and biofuels</i>	14%	2%	3%	8%	46%	0%
<i>Nuclear heat</i>	46%	4%	0%	2%	0%	0%
<i>Other</i>	2%	1%	89%	2%	2%	0%

Source: own calculations based on data from (Eurostat, 2024).

In the first cluster, there were eleven countries with the highest energy production volume (on average, 11 976 [ktoe]). At that time, the largest energy source in these countries was nuclear heat (46%), followed by solid fossil fuels (26%). Renewables and biofuels reached, on average, a 14% share. The second-highest energy production had, on average, five countries in the fifth group. They relied visibly on renewables and biofuels (46%). The second source was oil and petroleum (24%). Poland and four other countries were placed in the second group, which was placed in the third position regarding production size. Still, the average energy production in this group was more than half less than that of the first group. This group's primary energy source was solid fossil fuels (78%), followed by oil and petroleum products (14%). The four countries in the fourth cluster did not have much lower average energy production than the second cluster. The fourth group's primary energy source was solid fossil fuels (40%) and natural gas (38%), followed by oil and petroleum products but only at 11%. The third group consisted of only two countries that did not rely on any leading energy sources. At the same time, they had the second-lowest average production (the fifth position). Interestingly, solid fossil fuels were not used in this group at all. Finally, the last cluster that produced the least amount of energy consisted of only Cyprus, which used only oil and petroleum as energy sources. Cyprus was in a separate group due to the unique, quite different conditions of this country, which is actually an island, from the rest of the EU members. However, care was taken not to exclude any of the 27 countries from the analysis as long as possible.

Thus, the first group of countries can be described as a nuclear-based group, the second – based on solid fossil fuels, the fourth – based on solid fossil fuels combined with natural gas, and the fifth – based on renewable energy sources. In addition, the third group was based on other sources.

Energy mix in 2022

To see how changes in the energy mix have evolved over 32 years, the same analysis was carried out for the latest year of the study period: 2022. In Figure 6, the cluster dendrogram for the 2022 year was presented. This time, the countries were also divided into six groups, as presented in Table 7.

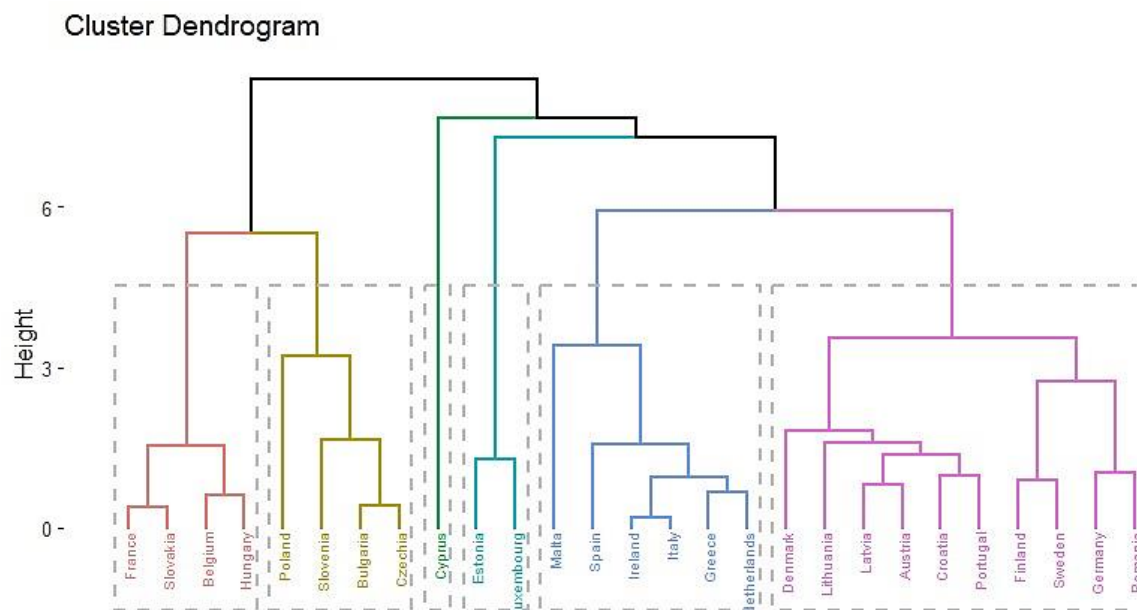


Figure 6. Results of Cluster Analysis for energy mix in 2022.

Source: own calculations.

Table 7.

Countries in each cluster for 2022

Cluster	Country
1	Belgium, France, Hungary, Slovakia
2	Bulgaria, Czechia, Poland, Slovenia
3	Denmark, Germany, Croatia, Latvia, Lithuania, Austria, Portugal, Romania, Finland, Sweden
4	Estonia, Luxembourg
5	Ireland, Greece, Spain, Italy, Malta, Netherlands
6	Cyprus

Source: own calculations.

Table 8 displays the average total production and shares in the clusters.

Table 8.

The average share of individual energy sources in clusters for 2022

Cluster	1	2	3	4	5	6
Average production [ktoe]	13 614	7 066	9 104	480	11 278	453
Solid fossil fuels	4%	45%	8%	0%	7%	0%
Natural gas	16%	5%	15%	3%	48%	0%
Oil and petroleum products	1%	1%	2%	0%	4%	83%
Renewables and biofuels	23%	21%	62%	39%	35%	17%
Nuclear heat	53%	28%	9%	0%	4%	0%
Other	3%	2%	5%	59%	2%	0%

Source: own calculations based on data from (Eurostat, 2024).

The countries with the most significant energy production on average were placed in the first cluster. There were four countries in this group. Their primary energy source was nuclear heat (53%). However, it was followed by renewables and biofuels this time, which accounted for an average of almost a quarter of the mix (23%). The second-largest production level had four countries in the fifth cluster. These countries relied mainly on nuclear energy (48%) but also more than a third on renewables (35%). The third rank obtained ten countries of the third cluster. After all, renewables were this group's first energy source (62%). They were followed by natural gas but only at 15%. Four countries in the second cluster, including Poland, had the fourth-highest energy production on average. Fossil solid fuels still had the largest share in this group (45%). However, it can be noted that the shares of nuclear power (28%) and RES (21%) were not so small. The last two by production volume were specific groups. The fourth cluster consisted of only two countries, Luxembourg and Estonia, as the third cluster in 1990. As before, their primary energy sources were quite different from those of the other countries (59%). However, it is worth noting that their share of RES increased noticeably to 39%. And sixth place was Cyprus, with oil and petroleum products being the basic energy source (83%). However, RES took second place in its energy mix (17%).

Thus, the first group contained nuclear-fueled countries; the second group consisted of solid fossil fuels-based countries. The third cluster was based on RES, the fourth on other sources, and the fifth on natural gas. It can be said that in the third group of countries, renewable energy sources were the most developed. Still, the fact is that in each of these groups, they were at a reasonably high level – over 20%. Its share increased unquestionably.

To conclude the analysis, the countries were again grouped separately for the years 1990 and 2022 in terms of the structure of the RES.

RES structure in 1990

Although by 1990, RES were not yet developed, an attempt was made to perform a cluster analysis of EU countries nonetheless. As three countries (Estonia, Cyprus, and Malta) had no renewable energy sources at all at that time, they were excluded before the procedure was started to allow for calculations. Figure 7 presents the outcome of the analysis.

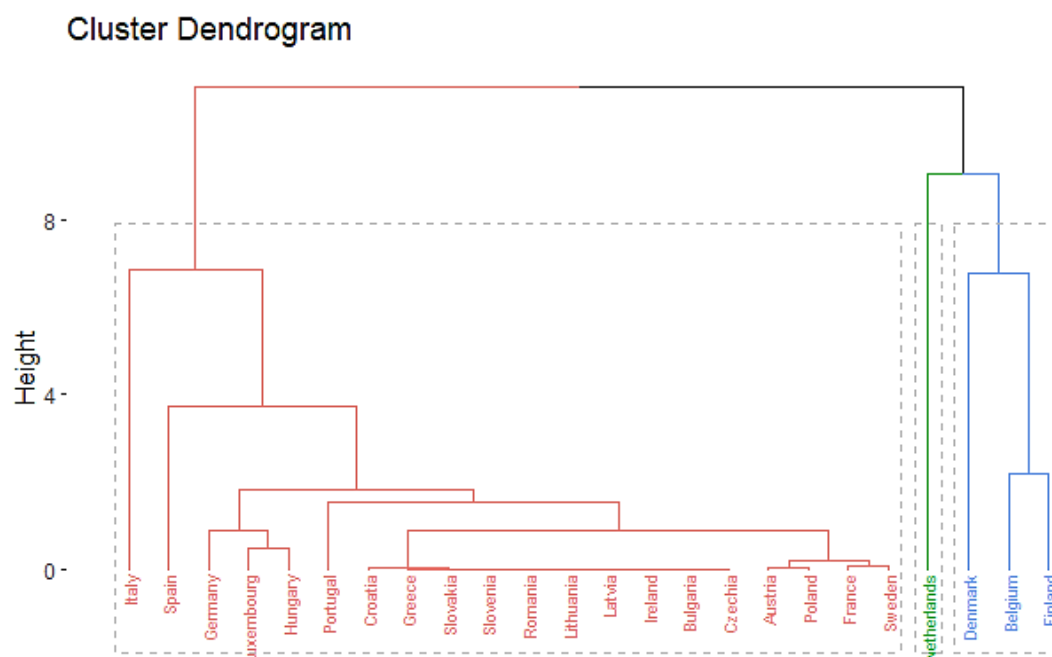


Figure 7. Results of Cluster Analysis for RES Structure in 1990.

Source: own calculations.

This time, the countries were divided into three clusters. The fourth group consists of Estonia, Cyprus, and Malta, not to omit any item. The clusters are listed in Table 9.

Table 9.

Countries in each cluster for RES in 1990

Cluster	Country
1	Belgium, Denmark, Finland
2	Bulgaria, Czechia, Germany, Ireland, Greece, Spain, France, Croatia, Italy, Latvia, Lithuania, Luxembourg, Hungary, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Sweden
3	Netherlands
4	<i>The group without RES (excluded): Estonia, Cyprus, Malta</i>

Note: the underlined countries were already members of the EU at that time.

Source: own calculations.

Table 10 presents the average total production from RES and shares of seven sub-categories in the clusters.

Table 10.

The average share of individual RES in clusters for 1990

Cluster	1	2	3	4
Average production [ktoe]	499	1 220	69.3	0
Hydro	40%	97%	11%	-
Geothermal	-	0.5%	-	-
Wind	25%	0.03%	7%	-
Solar	0.001%	0.003%	0.05%	-
Primary solid biofuels	23%	1.1%	4.3%	-
Biogases	2%	0.1%	11%	-
Renewable municipal waste	10%	1.6%	67%	-

Source: own calculations based on data from (Eurostat, 2024).

As many as 20 countries from the second cluster produced the most significant average volume of energy from RES. At the same time, its source was almost only hydro (97%). In the first cluster, with more than two times lower average production level, there were only three countries. Their RES structure consisted of hydropower (40%), wind power (25%), and primary solid biofuels (23%). The Netherlands was isolated as the third cluster with the lowest and most scarce production. It used then renewable municipal waste at most (67%). Biogades and hydropower were at 11%. As said before, the fourth group contained three countries without energy from RES.

Thus, the first cluster’s countries relied mainly on hydropower combined with wind and primary solid biofuels, and the second cluster relied almost entirely on hydropower. Solar energy was almost not used at that time.

RES structure in 2022

In Figure 8, cluster analysis results regarding 2022 are displayed. This time, all the countries were divided into three groups, listed in Table 11.

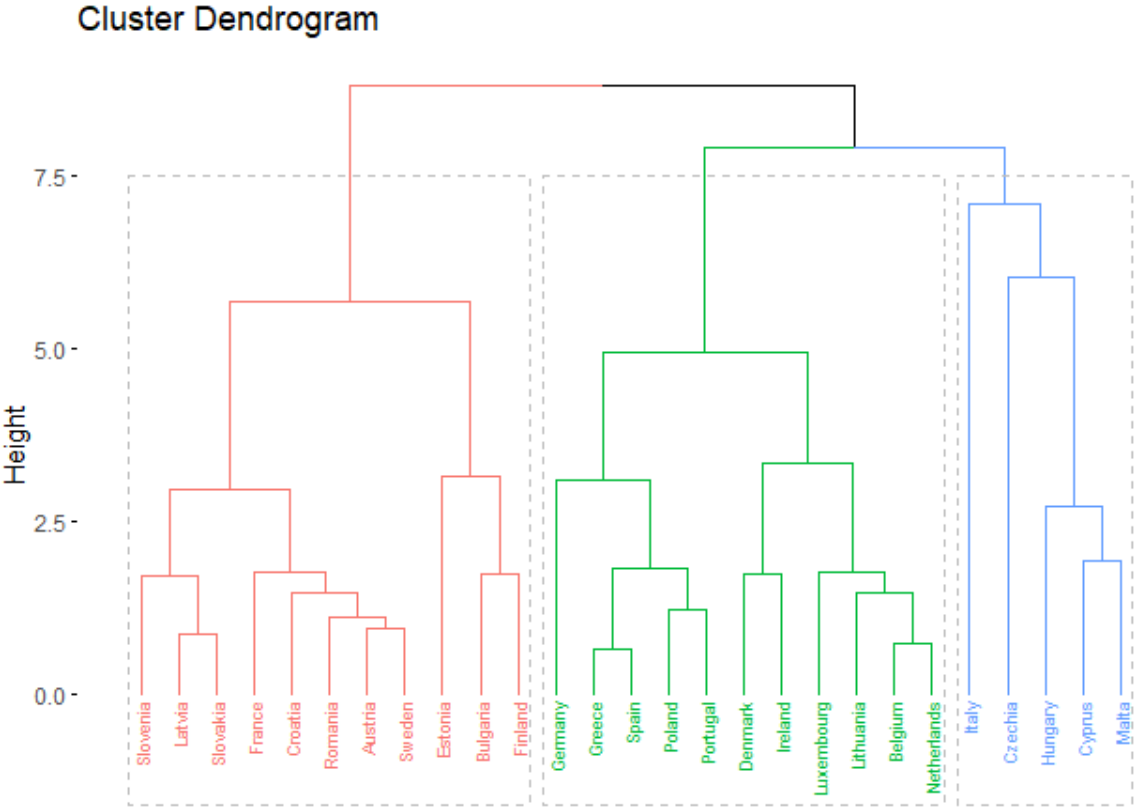


Figure 8. Results of Cluster Analysis for RES Structure in 2022.

Source: own calculations.

Table 11.
Countries in each cluster for RES in 2022

Cluster	Country
1	Belgium, Denmark, Germany, Ireland, Greece, Spain, Lithuania, Luxembourg, Netherlands, Poland, Portugal
2	Bulgaria, Estonia, France, Croatia, Latvia, Austria, Romania, Slovenia, Slovakia, Finland, Sweden
3	Czechia, Italy, Cyprus, Hungary, Malta

Source: own calculations.

Table 12 presents the average total production and shares in the clusters.

Table 12.
The average share of individual RES in clusters for 2022

Cluster	1	2	3
Average production [ktoe]	4 535	2 967	2 065
<i>Hydro</i>	9%	52%	10%
<i>Geothermal</i>	0.1%	0.1%	1%
<i>Wind</i>	53%	19%	12%
<i>Solar</i>	21%	10%	56%
<i>Primary solid biofuels</i>	11%	16%	10%
<i>Biogases</i>	4%	2%	9%
<i>Renewable municipal waste</i>	3%	1%	1%

Source: own calculations based on data from (Eurostat, 2024).

The highest level of electricity and heat derived from RES had eleven countries placed in the first cluster, including Poland. In these countries, over half of the output from RES was wind power (53%). It was followed by solar energy (21%). Hydro was also at the level of 11%. Eleven other countries of cluster two ranked second in energy production. Water was there the most important renewable energy source (52%). In 19%, it was also the wind; at 16%, it was the primary solid biofuel. The group with the comparatively lowest production from RES was cluster three, containing five countries. As much as 56% of this production came from solar energy. 12% was provided by wind, and 10% each came from hydropower and primary solid biofuels.

Thus, the first group relied mainly on wind power, the second on hydropower and the third on solar energy.

4. Discussion and summary

The analysis concluded that there has been a significant increase in the share of renewable energy sources in EU countries in recent years, confirming numerous previous studies documented in the literature. When observing the changes that have taken place in the structure of the energy mix from 1990 to 2022, one can see a rather significant decline in the percentage use of fossil fuels while the share of renewable energy sources has flourished. It has changed from 25,959 to 92,844 [ktoe] (258%), and in the energy produced share from 13% to 38%

(188% rise). Poland, too, has seen a significant increase in RES participation in recent years, confirming the results of earlier studies for example (Mularczyk, Zdonek, 2022; Wolniak, Skotnicka-Zasadzień, 2022, 2023; Zdonek et al., 2022; Świdyńska, 2024). At the same time, the consumption of fossil fuels has decreased, confirming studies that confirmed research (Rybak et al., 2024). However, they are still the dominant energy source (their share was about 70% in 2022), which is related to the long and complicated decarbonisation process of the hitherto coal-based economy, as previously described by (Jonek-Kowalska, 2022; Kaczmarek, Kolegowicz, Szymła, 2022; Jorge-Vazquez et al., 2024).

The results of the cluster analysis also confirmed those conclusions. In 1990, there were 6 groups of countries. In as many as two, fossil fuels dominated the energy mix (for solid fossil fuels and oil and petroleum products together, on average, from 51-92%): a total of eight countries. In these two clusters, renewables share was from 2 to 8%. One country relied exclusively on oil and petroleum products with no RES at all in its energy mix. Eleven countries were dominated by nuclear energy (46%) and supported by fossil fuels (31%), with renewables at 14%. Two countries produced energy from different sources (89%), with RES at 3%. In contrast, RES was the basis of energy production (46%) in only five countries, which also used all fossil fuels at 37%. This pattern has changed significantly in 2022. Countries were also divided into six groups. However, in most of them, RES had at least 21% (except Cyprus alone, with 17% of renewables and 87% of oil and petroleum products share). RES was also at least a second-dominant energy source in five of six clusters. As many as eleven countries relied on renewables at 62% on average. Only in one cluster, consisting of four countries (including Poland), fossil fuels dominated (46%). Besides, except for Cyprus, fossil fuels were at 0 to 11%, which was quite an impressive change.

Upon closer examination of the RES structure, a rapid increase in some sources was apparent. In the EU, the primary energy renewable source in 1990 was hydropower, which covered 94% of production from RES. After thirty-three years of not changing in terms of volume, it became only 26%. Other RES, such as wind, solar, and others, appeared during this period. Wind energy gained the largest share in 2022 (39%), followed by solar (19%). Primary solid biofuels (8%) were in fourth place in participation. In Poland, similarly, the initial level of hydro has hardly changed in terms of the value of energy produced from it or has even increased. However, its share of the total RES mix fell from 96 to 5%. That was again due to the appearance of other RES sources and their rapid development. The largest share in 2022 had wind (52%), followed by solar (22%). It confirmed the research of (Wolniak, Skotnicka-Zasadzień, 2022, 2023), among others. Primary solid biofuels accounted for as much as 16%.

Also, cluster analysis shed more light on the situation. In 1990, almost all countries relied on hydropower (except the Netherlands, relying on renewable municipal waste). However, three countries also had wind and primary solid biofuels at a reasonably high share level. Solar energy was practically not in use. In 2022, on the other hand, three groups of EU countries could be distinguished. The first group relied mainly on wind power, the second

on hydropower, and the third on solar energy. At the same time, the shares were more than 50% each time. Poland was in the group relying mainly on hydropower.

Studies have confirmed a significant increase in the share of RES in the energy mix of the countries now members of the European Union. RES sources themselves have also developed quantitatively, changing their structure. A substantial increase was recorded in wind and solar energies. However, solid fuels still exist in EU countries, although in a noticeably smaller share. In particular, countries whose economies are based on coal, including Poland, continue to rely on them as the primary energy source, even though they have visibly reduced their share in the mix. However, the unquestionable increase in RES is evidence of a good direction of their development.

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