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Development of Greenhouse Gas Emission and Evaluation of Carbon Resource Use in Chosen EU Countries

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Abstract: The EU presently orientates its policy to a low-carbon and resource-efficient economy. In this paper, we evaluate the current situation and the developments in greenhouse gas emissions, and we will evaluate carbon resource usage in chosen EU countries from the viewpoint of greenhouse gas emission per capita, energy production in the EU, energy dependence of EU countries, and final energy consumption. We will analyze and evaluate the data available from the Eurostat database through regression and cluster analysis using JMP 15 statistical software. The results show significant differences in the individual countries, and they can be used for determination of the energy policy in the individual states.

Keywords: carbon use; greenhouse gas emissions; EU energy policy; resource-efficient economy

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1. Introduction

The Energy Union is orientated toward an economy with low-carbon practices and effective use of resources, with the aim of sustainable development. Therefore, it accepted related initiatives in the legislative framework supporting such an economy. In this regard, the European Council accepted three main goals by 2030: at least a 40% decrease in greenhouse gas emission (from the level in 1990); at least 27% energy rate from renewable energy sources (RES); and at least a 27% increase in energy efficiency. The European Commission suggested increasing energy efficiency [1].

The relevant EU policy mirrors the Europe 2020 strategy, which emphasizes reducing energy consumption and increasing energy efficiency. The energy productivity of the economy is a key indicator for measuring the Lisbon process and its successor in the Europe 2020 strategy, helping to identify the balance between energy consumption and economic growth.

Energy dependence on energy imports and the present geopolitical problems expose the European economy to volatile prices and the risk of supply issues. The Europe 2020 strategy has a goal to lower energy dependence through risk management, as well as a goal to increase the share of renewable energy in gross final energy consumption. By 2030, this share should be 27% (2030 Climate and Energy Policy Framework). The Energy Union Strategy considers renewable energy as part of the energy system decarbonization.

The goal of the present study is to research the development of the aforementioned indicators in the EU and evaluate the achievement of these goals at the present time. This research presents another area of the authors' research, orientated to resource use, previously studied mainly in the area of waste and water use efficiency. The research presented here is orientated to another resource use—carbon footprint. The goal is achieved by an analysis of individual indicators, which presents resource use efficiency, mainly in chosen EU countries, as well as their development over time, as follows: greenhouse gas emissions per capita, energy production and energy dependence, and renewable energy source rate on gross final energy consumption.

2. Present State of Problem Solving

Ecological balance and the economy, orientated toward a decrease in carbon use, attracted increased attention in relation to a global warming solution. A number of authors studied the development of carbon resource use, mainly from the view of CO_2 emissions. Bohringer and Lange created optimal schemes for free emission allowance allocation, mainly from a dynamic point of view, considering rules for emission allocation according to performance [2]. In a closed system for business with an absolute level of emissions, the primary system is to allocate quotas directly according to the previous emissions. In a system of open business, the primary systems of allocation do not have to be dependent on decisions of an organization. On the other hand, the secondary systems of allocation correspond to the rule of optimal tax differentiation. They are generally based on the level and creation of emissions in the past. Since environmental limitations on economic growth are increasing, a decrease in allocation of carbon emissions (CEA) is becoming a very important problem, attracting attention in the academic area [3]. Zeng et al. analyzed indicators of carbon emission effectiveness, mainly in static and dynamic states, and they found regional differences where there is ample room for improving carbon emission effectiveness. This is possible in the case when regional industrial structure, energy dependence, and urbanization have an important influence on the effectiveness of the carbon emission [4].

Several recent papers propose competing theoretical explanations for the empirical observation of an inverted U-shape relationship between environmental degradation and per capita income. A test proposed by Bartz and Kelly, supported the theory that the inverted U-shape results from a corner solution in which less developed countries do not abate pollution [5]. However, because decreasing pollution is relatively inexpensive, the model predicts pollution peaks at a level of per capita income much lower than that observed in the case of the USA. Improvements should be made in mutual carbon reduction as a more accepted way of global warming reduction, not only from the view of emission performance but also from the view of cost effectiveness of the emission reduction. Therefore, He et al. analyzed the cost savings and contributions for mutual emission reduction in China. They found every region had a contribution to the cost saving in this case [6]. Wu et al. found the majority of municipalities in eastern China and several municipalities in the western part could be the main purchasers of carbon credits (allowances) at the national market with carbon emission business [7].

Industrialization ranks among the primary indicators of increased CO_2 production, mainly by electricity consumption and burning of fossil fuels. Fernando and Hor [8] found that processes for energy management are still not developed. Among industrial companies, there is generally insufficient competition and/or pressure to develop environmental management plans. Only marginal improvement of energy management and energy effectiveness is obvious. Energy audit and energy efficiency present two critical factors for carbon emission reduction. Ahmed provides similar research, proving there is a slowing down in the contribution of the total factors of productivity growth, as well as negative influence of CO_2 emissions, produced mainly by the industrial sectors [9].

Moreover, Du et al. studied a situation in China, mainly through emissions development and potential to reduce carbon emissions in China. They showed that economic and technology development, Začiatok formulára Spodná časť formulára as well as industry structure, represent the most important factors that influence carbon emissions in China. On the other hand, influence of energy consumption, trade, and urbanization can be considered as not important [10].

Carbon storage is affected also by production of wood energy. In this area, Armento suggested possible scenarios when determining that U.S. forests store less carbon, considerably differentiating their role in the global warming solution Začiatok formulára [11]. Huang et al. (2020) conducted a review of publications orientated to the forest carbon sequestration, wherein they showed that this field has an increasing trend, with publications orientated mostly toward the areas of the USA, China, and Canada [12]. The authors focused their research mainly on the changes in the carbon storage and contribution to the ecosystem. A similar review of the literature was conducted by Ali and Yan to explore carbon stocks in different forest ecosystems, and they found that little is understood regarding how multiple measures of biodiversity affect carbon stocks when considering biotic and abiotic components of an ecosystem [13]. The present global environment, mainly climate change, demands new approaches to the management of ecosystems, with an aim to improving the subsequent productivity in agro systems. In this area, Lugoi et al. used a simplified integrated approach to model productivity. The model emphasizes that carbon emissions are influenced by climatic, topographic, vegetation, and soil attributes [14] (similar results provided by [15]).

3. Materials and Methods

The goal of this paper is to evaluate the development of indicators established by the European Commission for monitoring the efficiency of resource use from the viewpoint of carbon resources. In this context, the target values of the countries were defined according to the following indicators:

- greenhouse gas emissions,
- energy productivity,
- energy dependence,
- RES share on gross final consumption of energy.

These indicators were analyzed in the framework of individual analyses and summary analysis, the aim of which was to define the level of results for the countries as well as for the EU as a whole. In conclusion, using cluster analysis, homogeneous groupings of countries achieving similar results within the monitored energy indicators were created, which can serve in the formation of methodologies leading to target values.

Results presented in the contribution relate to data from the publicly available database—Eurostat. The data are subsequently analyzed and processed in statistical software JMP 15 (produced by © SAS Institute Inc., Cary, NC, USA) Data were collected for all EU countries for all available years. There were 3416 datapoints collected for the period 1990–2020. Analysis was performed according to the following process:

1. Graphical analysis of greenhouse gas emissions per capita in EU—cartographer
2. Regression analysis of greenhouse gas emissions per capita and time
3. Graphical analysis of energy productivity in EU—cartographer
4. Regression analysis of energy productivity and time
5. Graphical analysis of energy dependence in EU—cartographer
6. Analysis of variability of energy dependence according to the countries—Kruskal–Wallis test
7. Graphical analysis of renewable energy sources (RES) rate on gross final energy consumption in EU—cartographer
8. Analysis of variability of RES rate on gross final energy consumption according to the countries—Kruskal–Wallis test
9. Regression analysis of RES rate on gross final energy consumption in EU and time
10. Cluster analysis

3.1. Regression Analysis

Regression analysis was used during this research, according to the formula:

$$Y = \beta_0 + \beta_1 X + e \tag{1}$$

where Y—dependent variable; X—independent variable; β_0—model parameter: localization constant, determines what the Y value will be when X equals zero; and β_1—model parameter: regression coefficient, denoting the slope of the regression line.

The parameter gives information regarding how Y will change when X changes by 1 unit

$\beta_1 > 0$ positive dependence
$\beta_1 < 0$ negative dependence

3.2. Kruskal–Wallis Test

We used the Kruskal–Wallis test during this research. The importance of this test results from the situation when the one-way ANOVA approach (analysis of variance) does not meet the assumptions (in ANOVA, the dependent variable should be normally distributed, and the deviation between the individual groups should be approximately the same). In the Kruskal–Wallis test, there are not such assumptions. The Kruskal–Wallis test evaluates significant differences in the dependent variable, mainly through the independent variable. Therefore, the Kruskal–Wallis test was used for constant and ordinal dependent variables.

3.3. Cluster Analysis

Cluster analysis performs clustering of the points close to each other that have similar values. In Ward´s method, used for minimum variance, the distances between two clusters represent the ANOVA sum of squares between two clusters, summed up through all variables and indexes. The sum of squares in the context of a cluster minimized in all sectors can be obtained by clustering from the previous generation.

Ward´s method connects clusters with the aim of maximizing the probability at each level of hierarchy, assuming a multivariate normal distribution, spherical covariance matrix, and probabilities of equal sampling [16].

Ward's method has a tendency to connect the clusters with a small number of observations. It has a strong tendency to produce clusters with approximately the same number of observations.

The clusters are formed in the following way:

- the increase in the variability of the intro component "W" is small
- the increase of the inter-cluster variability "B" is large [17].

$$W = \sum_{j=1}^{k} W_j = \sum_{s=1}^{m} \sum_{i=1}^{k} (x_{si} - \overline{x}_s)^2 \quad (2)$$

$$B = \sum_{s=1}^{m} \sum_{j=1}^{k} k\left(\overline{x}_{sj} - \overline{x}_s\right)^2 \quad (3)$$

where $\overline{x}_s$—total diameter of the s-th cluster; and x_{si}—the value of the s-th cluster for the i-th variable.

3.4. Greenhouse Gas Emissions per Capita

The index of greenhouse gas emission per inhabitant is used for monitoring the process towards a carbon-effective Europe. The index measures total national emission of the so-called well-known "Kyoto basket" for a greenhouse gas, including CO_2, CH_4, N_2O, F-gasses (fluorocarbons), perfluorocarbons, NF_3, and SF_6. By individual potential of global warming (GWP) of any gas, the gasses mentioned above are integrated to the single index and expressed in CO_2 equivalents per inhabitant. The EU member states include annual data of emissions as a part of their reporting according to the UN Framework Convention on Climate Change [1].

The average number of inhabitants in the reference year is used as the denominator (per inhabitant), calculated as the arithmetic average number of the inhabitants on 1 January in two sequential years. The index does not include emissions that are connected with soil usage and its changes nor forest economy (LULUCF); it does not include emissions that are reported as additional element according to UNFCCC directives. However, the index includes emissions from the international aviation activity, as well as indirect CO_2 emissions. The unit of measurement is presented as ton of CO_2 equivalent per inhabitant [1].

3.5. Energy Productivity

The "Energy Productivity" indicator is another indicator making up the Resource Efficiency Scoreboard to control resource-efficient Europe, complementing the carbon index [18].

The index presents a result of the GDP rate on gross domestic energy consumption in the analyzed year. GDP in Eurostat is expressed as purchasing power standard (PPS) to calculate energy productivity. Gross domestic energy consumption is then given as the total gross domestic consumption of coal, electricity, oil, natural gas, and RES. Since GDP is measured in millions of PPS and gross domestic consumption is measured in thousands of tons of oil equivalent, energy productivity is available in PPS per kg of oil equivalent. Currency unit: PPS per kg of oil equivalent [19].

3.6. Energy Dependence

The "Energy Dependence" index forms part of the Resource Efficiency Scoreboard for monitoring a carbon-efficient Europe. It shows the extent to which the economy relies on imports to meet its energy needs. It can be calculated as follows:

Energy dependence = net import/$\sum$ gross final energy consumption + international marine storage.

Net import = total import − total export.

Gross final energy consumption = Domestic production + Stocks of other sources + Import–export–international marine storage + change in stocks.

Energy dependence can be negative for net exporters, while positive values over 100% means accumulation of stocks during the reference year. The index is measured as percentage import rate of total energy consumption [20].

3.7. RES Rate on Gross Final Energy Consumption

RES rate on gross final energy consumption presents a part of the resource efficiency evaluation for monitoring a resource-efficient Europe. The index measures the RES consumption rate on gross final energy consumption according to the Renewable Energy Directive. Gross final energy consumption presents the energy used by final consumers plus network losses and self-consumption of power plants in percentage [21].

4. Results

4.1. Greenhouse Gas Emissions per Capita

The first indicator monitoring progress towards a Europe that efficiently uses resources in the area of carbon is the Greenhouse Gas Emission per Capita indicator. In an effort to fulfill the objectives of the EU's environmental policy, the goal of each country is to reduce the value of this indicator. With the use of cartographers, it was possible to compare the states (see Figure 1) with each other in 2010, as well as to evaluate the change at the level of individual countries after 10 years (until 2020).

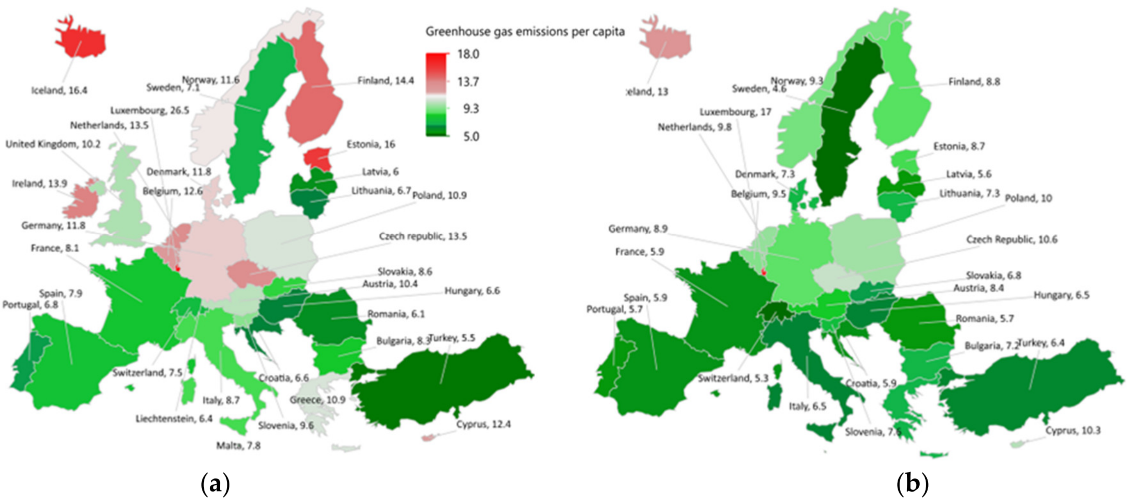


Figure 1. Cartographid representation of greenhouse gas emissions per capita in EU member states: (**a**) in 2010 and (**b**) 2020. Source: own processing according to [22], processing in JMP. Note: The legend applies to both (**a**,**b**).

The countries with the highest production of emissions per capita in 2010 include Luxembourg (26.2), Iceland (16.4), Estonia (16), Ireland (13.9), and Finland (14.4); significant producers of emissions also include the Czech Republic and the Netherlands, each with an indicator value of 13.5. By comparing these results with the year 2020, it is possible to see a significant reduction in emission production for most countries, but Luxembourg continues to maintain its lead, with an indicator value of 17, despite the highest reduction in emission production by up to 9.2. By analyzing the data on the production of emissions per capita in the EU member states published in the Eurostat database for the years 2000–2020, we can see that, on average, this indicator is decreasing by 1.18% per year (Figure 2) for the European Union, but it is questionable whether this will be sufficient to meet the EU's goals.

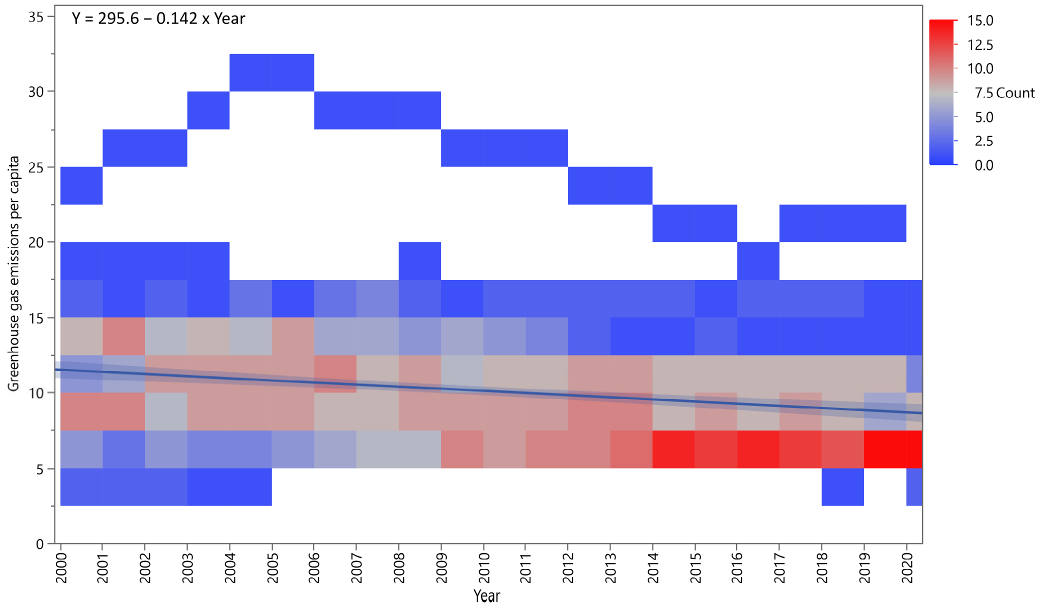
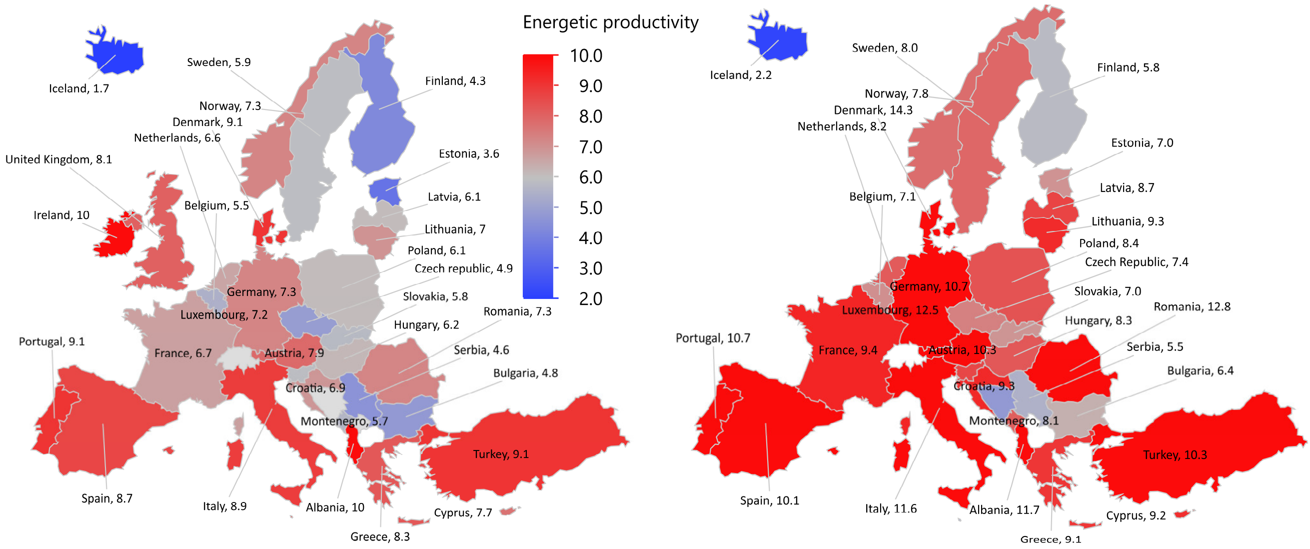


Figure 2. Development of greenhouse gas emissions per capita in 2000–2020 in EU. Source: own processing according to [22], processing in JMP.

4.2. Energy Productivity

The energy productivity indicator is another of the indicators monitoring Europe's progress in the area of carbon activity. Increasing energy productivity is one of the main goals of the Europe 2020 strategy. The indicator is determined as a share of GDP in the unit purchasing power standard (PPS) and gross domestic energy consumption expressed in kg of oil equivalent. By analyzing the achieved values of this indicator for the member states of the European Union published in the Eurostat database for the years 1995–2020, it was possible to assess the development trend of the indicator at the level of the European Union, as well as the development within individual states. The following cartographic representations clearly show the situation in individual states in 2020 and offer a comparison with 2010.

The same range of values was deliberately chosen for both cartographies, in this case adapted to 2010, which means that the energy productivity ranged from 2 to 10 PPS/kg of oil equivalent. In 2010, only Ireland and Albania were at the level of the maximum of this interval. Ten years later, 11 states reached or exceeded this maximum limit of 10 PPS/kg (Figure 3). This indicates a significant shift in countries towards increasing energy productivity. The analysis of the development of the indicator for the period from 1995 to 2020 at the level of the European Union proved a growing trend expressed through the linear regression model Y = −421.8 + 0.2134*Year, on the basis of which it was possible to derive a year-on-year increase in energy productivity of 6% (Figure 4).



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

Figure 3. Cartographic representation of energy productivity of EU member state in: (**a**) year 2010 and (**b**) year 2020. Source: own processing according to [19], processing in JMP. Note: The legend applies to both (**a**,**b**).

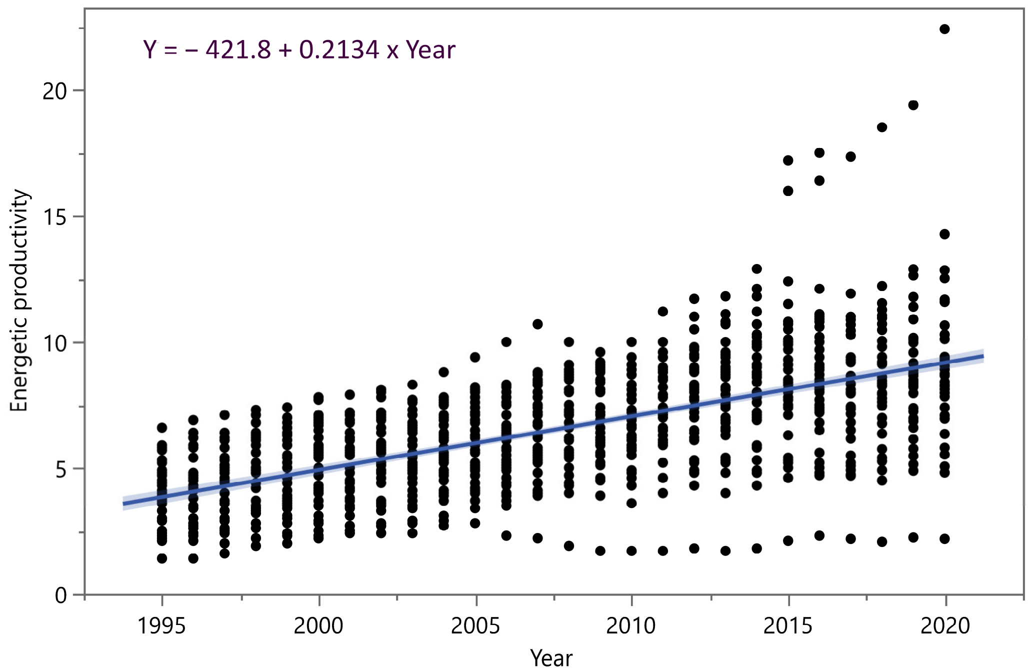


Figure 4. Development of energy productivity in EU in 1995–2016. Source: own processing according to [19], processing in JMP.

A simple linear regression model (Figure 4) was used to define the time evolution of the indicator. Our goal in this section was not to define the reasons for this trend, for which multiple regressions would certainly be appropriate. Outliers represent the development in two countries from 2015–2020; these are Ireland and Malta. These countries achieved higher productivity than other EU states, but a significant impact on the defined regression model cannot be confirmed; even after excluding these values and re-analyzing the data, the annual development trend is maintained at the level of approx. 6%. For example, in 2018, final energy consumption in Ireland (excluding international aviation) was 11.2 Mtoe, 10% higher than in 2000. The transport sector was responsible for the largest increase in energy demand. It increased by 17% over the period, and in 2018, accounted for 37% of all final energy use, up from 34% in 2000. The next largest sector was households, accounting for 25% of final energy use. In 2018, household energy use was 11% above that of 2000. Industry energy use accounted for 23% of final energy use in 2018 and was 2% higher than in 2000. While the annual consumption of electricity in Malta is less than 2500 GWh, with the rapid increase in tourism, economy, and population, the demand for electrical generation is rising. Malta has worked to diversify and modernize its electrical grid in recent years, transitioning from inefficient coal and heavy-oil-fueled domestic production to an approach using natural gas, oil for backup, and an electricity interconnector.

4.3. Energy Dependence

The Energy Dependency indicator expresses the state's degree of dependence on the import of energy carriers; it represents the ratio of net imports to gross domestic energy consumption. The effort of the European Union is to reduce energy dependence. On the basis of the data on the energy dependence of EU member states for the period 1990–2020 published in Eurostat databases, the development of individual states, as well as the direction of the European Union, can be assessed. At the same time, it is possible to evaluate the fulfillment/non-fulfillment of the goals to which individual countries have committed themselves.

Graphical analysis using a cartographer (Figure 5) defines Norway as the only country that is not energy dependent on the import of energy carriers. The values of the indicator are negative, which means that the export of energy carriers in the country prevails over the import. For a better illustration of the results of other EU member states, Norway was excluded from further analyses (Figure 6). By comparing both cartographies, we can see a certain reduction in energy dependence after ten years, but at the same time, we can see that there was no significant structural change among the countries.

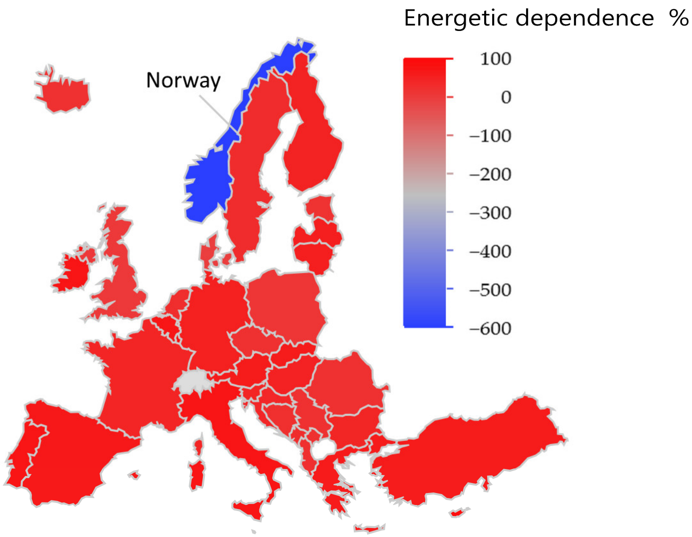
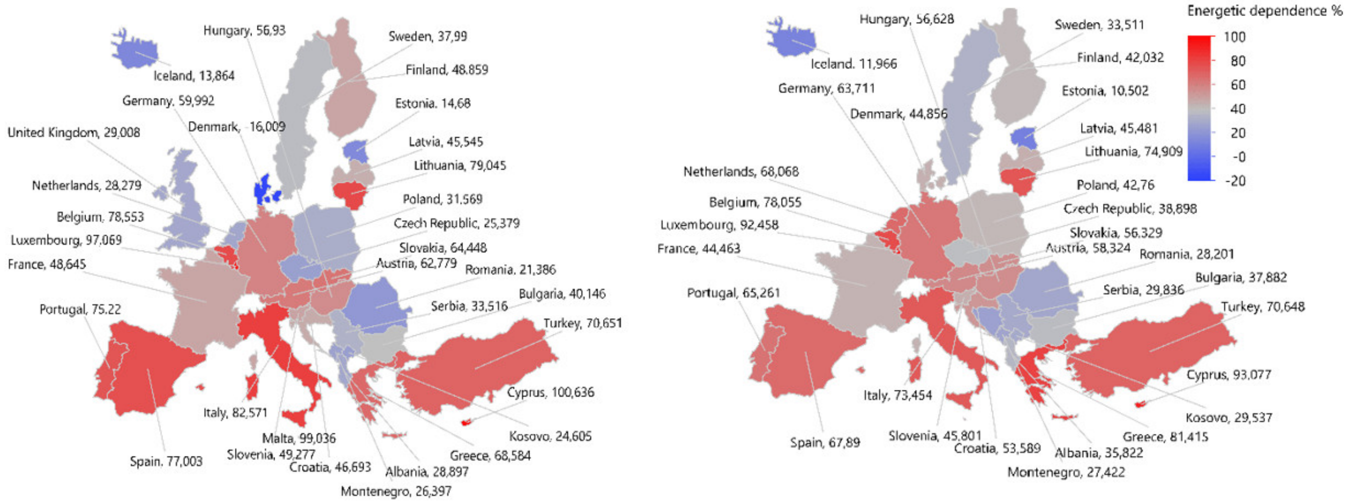


Figure 5. Cartographic representation of energy dependence for EU countries in average values in 1990–2006. Source: own processing according to [20], processing in JMP.

By using the Kruskal–Wallis test to analyze the variability of the indexes according to member states, it was confirmed that there exists a statistically important difference among EU member states (with p-value lower than 0.05) (see Table 1).



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

Figure 6. Cartographic representation of energy dependence in EU member states in: (**a**) year 2010 and (**b**) year 2020; excluding Norway. Source: own processing according to [20], processing in JMP.

Table 1. Analysis of variability for energy dependence by Kruskal–Wally's test.

Chi-Square	DF	Prob > Chi-Sq
901.5563	37	<0.0001

Source: own processing according to [20], processing in JMP.

This is illustrated by the following graph (Figure 7). On the basis of this, the states can be divided into three groups. The first group consists of states with high energy dependence exceeding the EU average for 2020, which is at the level of 53%; this includes Cyprus, Luxembourg, Malta, and Slovakia. The second group consists of countries with lower energy dependence than the EU average, namely the Netherlands, Poland, Romania, Serbia, and Sweden. The third category includes countries with a negative value of the indicator, namely Norway. The goal of the EU is to reduce energy dependence, but at the level of many states, this goal is not fulfilled, which also affects the growth of the average indicator for the EU. There are countries that have a high rate of energy dependence, and this rate continues to grow, as can be seen, for example, in the case of Turkey, Germany, Belgium, and Greece (which is represented by the red points, defining the latest years according to the legend).

The analysis of the development of the indicator at the level of the European Union for the monitored years, despite the goals set by the individual countries, defines an almost constant or lightly increasing trend, which is indicated by the graph in Figure 8.

4.4. RES Rate on Gross Final Energy Consumption

The RES rate on gross final energy consumption expresses the percentage of the energy consumed in the state that comprises energy from renewable sources. The European Union's effort is to increase the value of this indicator, with a goal of 20% that was set by 2020 as part of the Europe 2020 strategy; in the next period until 2030, this value was increased to 27%. On the basis of the values of the indicator for individual EU member states in 2020 published in the Eurostat databases, the results of individual states can be compared using the cartographer. The graphic analysis clearly favors the Nordic countries, in which the share of coverage of gross final energy consumption through RES ranges from 26.7 to 83.7% (Figure 9).

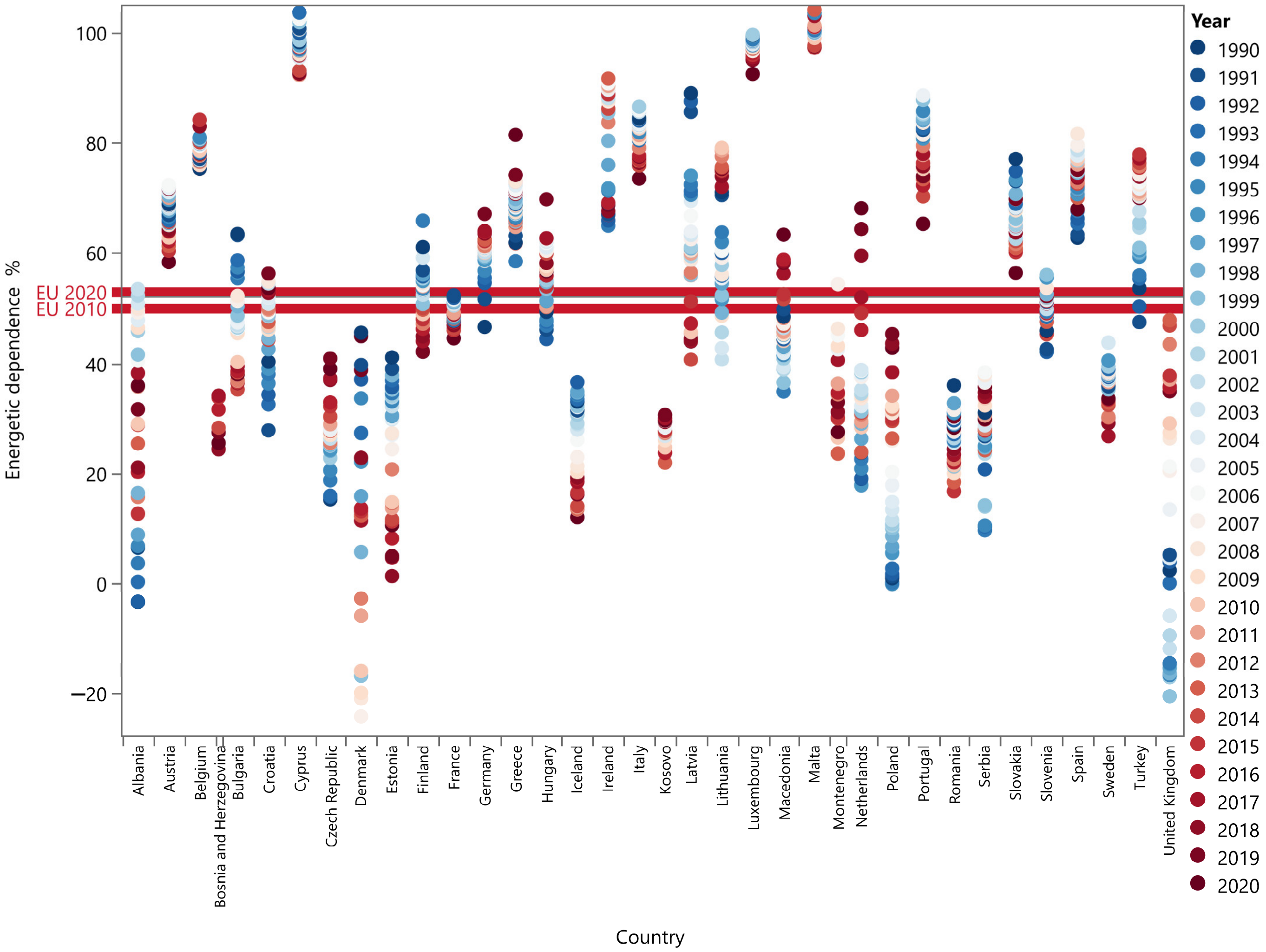


Figure 7. Energy dependence—graphical analysis of the variability according to EU member states, excluding Norway. Source: own processing according to [20], processing in JMP. Note: the present value of the index in a fixed year, according to the legend; countries are represented on the x-axis.

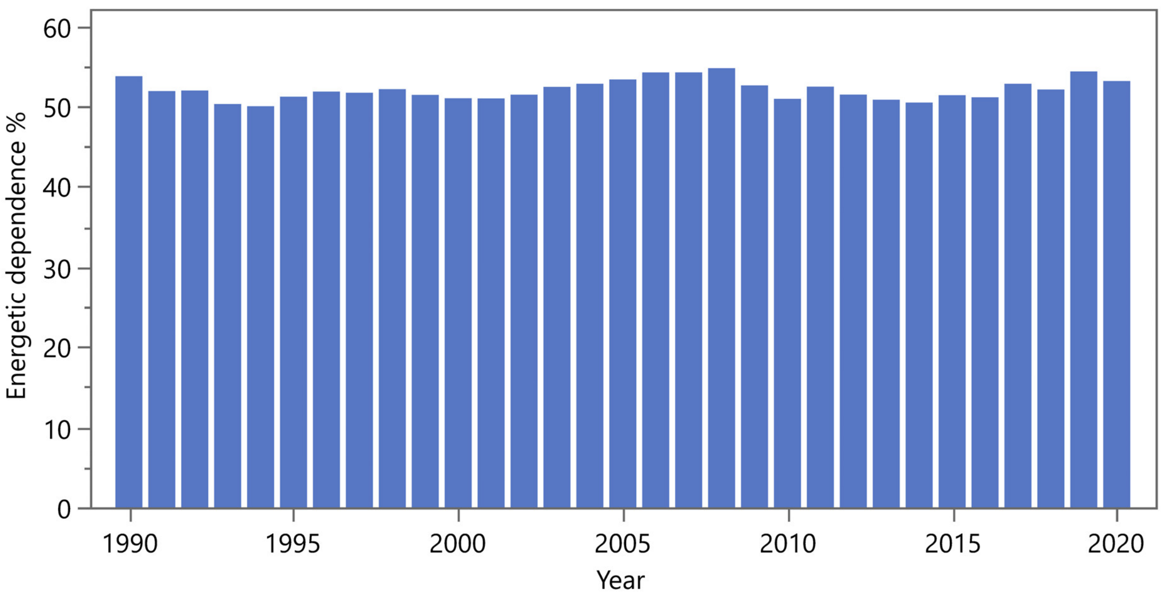


Figure 8. Average values of energy dependence in EU in 1990–2020. Source: own processing according to [20], processing in JMP.

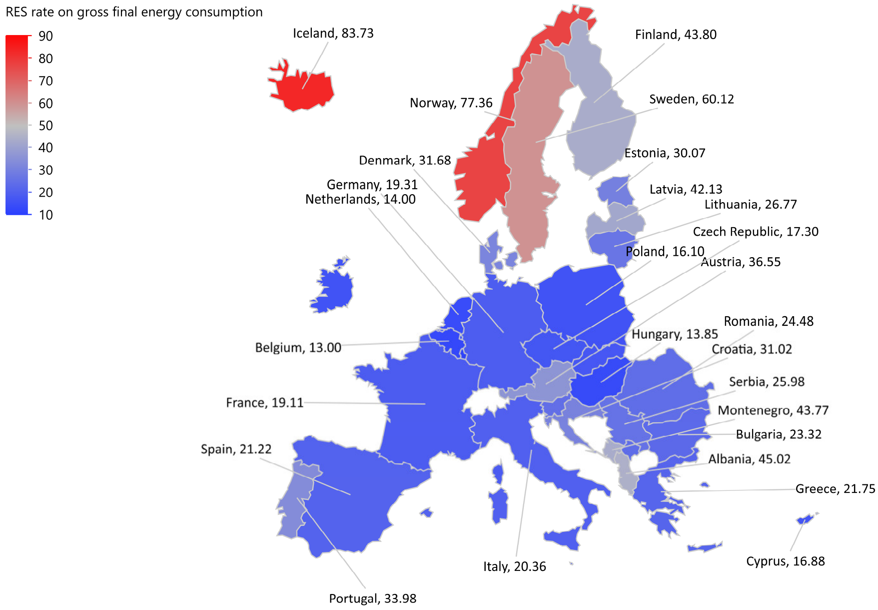


Figure 9. Cartographic representation of RES rate on gross final energy consumption in 2020. Source: own processing according to [21], processing in JMP.

At the same time, it is necessary to pay attention to the results of the Visegrad group-V4 countries, which did not exceed the value of 17.3% during the monitored period. The results of the graphical analysis show that there are significant differences among the results of the indicator at the level of individual states, which was confirmed by the analysis of variability using the Kruskal–Wallis test, which defines the differences among countries as statistically significant (Table 2).

Table 2. Kruskal–Wallis Test.

Chi-Square	DF	Prob > Chi-Sq
447.9985	39	<0.0001

Source: own processing according to [20], processing in JMP.

The development of the indicator for the years 2004–2020 within the EU shows a growing trend at the level of 0.775% per year, which represents an increase of more than 12% in the 16 analyzed years (Figure 10). The goals that were set as part of the Europe 2020 strategy can be assessed as fulfilled, on average, for the EU, but its fulfillment at the level of individual EU states is questionable.

Analyzing the results at the level of individual EU member states, a positive finding can be noted; all states in recent years show an increasing trend of the indicator, i.e., increasing the share of RES in gross final energy consumption. In 2020, there were still many countries that did not meet the goal—20% share of RES in gross final energy consumption. These countries include Belgium, Malta, Hungary, Slovakia, Poland, the Czech Republic, the Netherlands, Cyprus, and others (Figure 11).

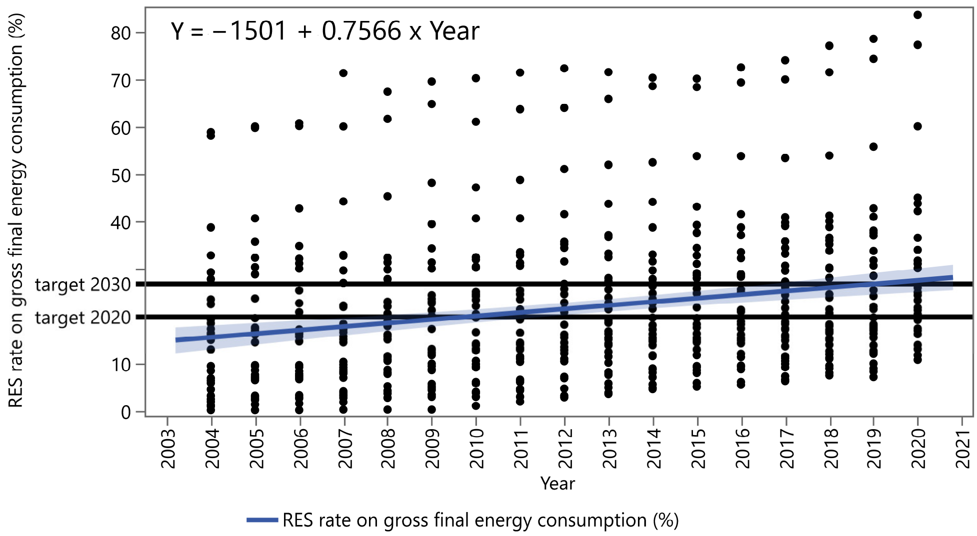


Figure 10. RES rate on final energy consumption in EU member states in 2004–2016. Source: own processing according to [21], processing in JMP.

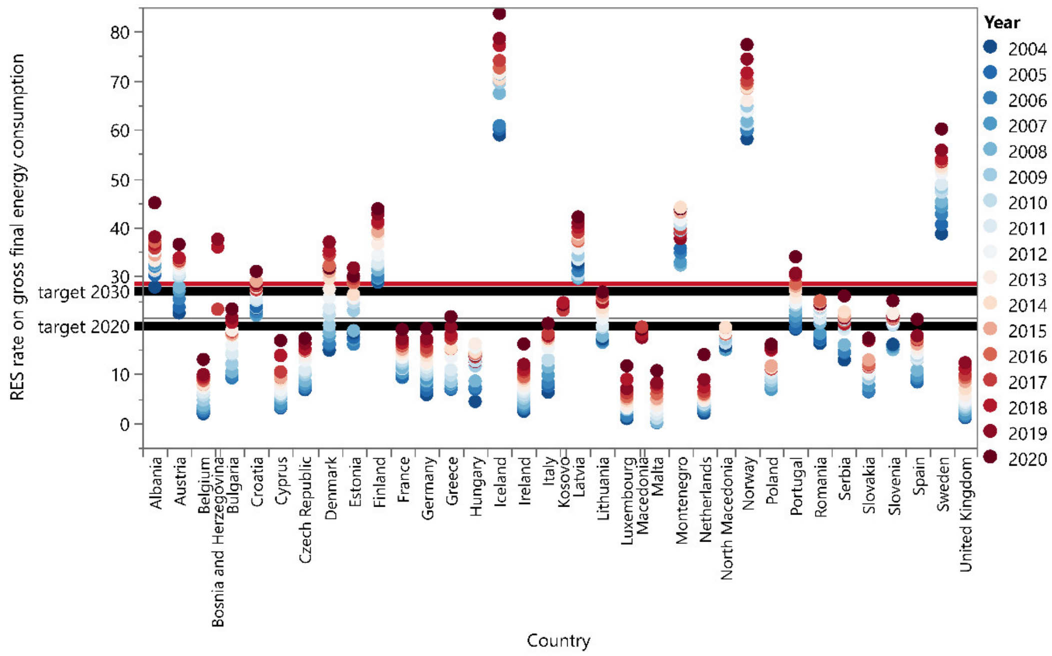


Figure 11. Graphical analysis of the variability according to the EU states—RES rate on gross final energy consumption. Source: own processing according to [21], processing in JMP. Note: the present value of the index in a fixed year, according to the legend; countries are represented on the x-axis.

5. Discussion

After analyzing each indicator separately, significant differences in the results of individual countries were found. On the basis of these findings, we used cluster analysis to look for common features of the states with respect to energy indicators and divided the analyzed objects into internally homogeneous groups. Ward's clustering method was used, creating four groups (Figure 12).

Production of carbon emissions, in spite of the efforts, is decreasing only slowly in the majority of countries, or it is not decreasing (Figure 1). This presents the reason for a rather rapid actualization of legislative measurements of the government's policies with a goal of achieving still more strictly the target values of chosen indexes—emissions of the greenhouse gas, energy productivity, energy dependence, and RES rate on gross final energy production. However, legislative measurements are not the only solution; the indicators also depend on technical solutions, structure of industries, states' own resources of energy raw materials, and other factors.

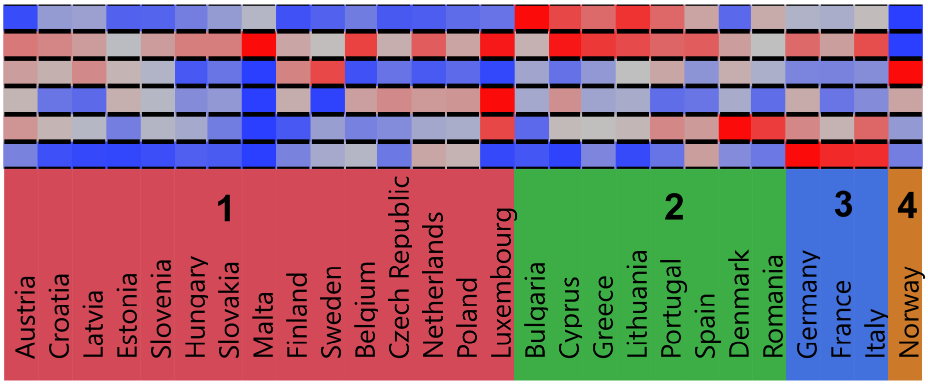


Figure 12. Cluster analysis. Source: own processing according to [19–22], processing in JMP.

Energy productivity depends directly on energy effectiveness of the transformation processes and energy consumption. From the aforementioned, we can state that energy effectiveness based on these processes is still increasing (Figure 3). An increase in energy productivity should mean gradual reduction of countries' dependence on energy imports. However, the analysis shows that the majority of EU states did not decrease their dependence on external energy sources; however, in several countries, energy dependence worsened (Figure 6). In Table 3, differences of the energy dependence in 2010 and 2020 are presented. An increase in energy dependence (negative values of the difference) is highlighted in red.

Table 3. Energy dependence of the country.

Year	Energy Dependence of the Country (%)											
	AL	AT	BE	BG	CY	CZ	DE	DK	EE	GR	ES	FI
2010	28.897	62.779	78.553	40.146	100.636	25.379	59.992	−16.009	14.68	68.584	77.003	48.859
2020	35.822	58.324	78.055	37.882	93.077	38.898	63.711	44.856	10.502	81.415	67.89	42.032
Difference	−6.93	4.46	0.50	2.26	7.56	−13.52	−3.72	−60.87	4.18	−12.83	9.11	6.83
Year	FR	HR	HU	IE	IS	IT	LT	LU	LV	ME	MK	MT
2010	48.645	46.693	56.93	87.484	13.864	82.571	79.045	97.069	45.545	26.397	44.005	99.036
2020	44.463	53.589	56.628	71.302	11.966	73.454	74.909	92.458	45.481	27.422	63.291	97.56
Difference	4.18	−6.90	0.30	16.18	1.90	9.12	4.14	4.61	0.06	−1.03	−19.29	1.48
Year	NL	NO	PL	PT	RO	RS	SE	SI	SK	TR	Z8	
2010	28.279	−512.833	31.569	75.22	21.386	33.516	37.99	49.277	64.448	70.651	24.605	
2020	68.068	−623.059	42.76	65.261	28.201	29.836	33.511	45.801	56.329	70.648	29.537	
Difference	−39.79	110.23	−11.19	9.96	−6.82	3.68	4.48	3.48	8.12	0.00	−4.93	

There are not only less-developed countries in the EU, but also industrially developed countries. Energy dependence had been increased in Poland, Czech Republic, Romania, Kosovo, Albania, Montenegro, Croatia, the Netherlands, Denmark, and Germany. This conclusion has been verified by the Kruskal–Wally's test.

With regard to the index of energy dependence mentioned above, we followed this up in our research, with an emphasis on the actual political and energy situation in EU and worldwide. It will still be necessary to follow up the development of the individual countries' dependence on the import of energy and to draw conclusions and make recommendations on the basis of the results of the analysis. Those should provide a very strict and consequent diversification of the energy sources, with an emphasis on maximizing the use of local renewable and alternative energy sources.

Mainly, RES and alternative energy sources are still a problem for EU countries, with the exception of northern countries, such as Norway, with 77% RES rate, followed by Sweden, with over 60%, and Finland, with over 43% RES rate on total energy consumption (Figure 8). Latvia and Austria follow closely behind them. A very important point is the high RES rate in the former countries of Yugoslavia, in which it is very problematic to verify the data given by Eurostat. The Kruskal–Wallis test also proved that the processes of EU countries in area of RES implementation to the energy mix are not unique, with a *p*-value of 0.0001, which means that differences between individual countries are very significant. In spite of this, in the EU as a whole, there is a noticeable continual increase of RES rate on total energy mix (Figure 10).

In spite of the mentioned differences, it is possible to evaluate individual EU countries, through cluster analysis (Figure 12). Four clusters have been created according to the states' meeting of the determined criteria.

Cluster 1 constitutes countries in which most indicators reach the average values of all EU countries.

Cluster 2 consists of countries with similar indicator values as countries in Cluster 1, but the energy poverty rate is high in these countries. The index measures the share of residents who cannot afford to maintain adequate heat in their homes. Data for this indicator are collected as part of the European Union statistics on income and living conditions (EU-SILC) to monitor the development of poverty and social inclusion in the EU.

Cluster 3 represents countries with above-average energy taxes. On the other hand, it is possible to state that the amount of energy taxes directly contributes to the increase of energy productivity and, thus, to the reduction of carbon emissions.

Norway forms Cluster 4, where energy dependence and RES rate on gross final energy consumption in this country greatly exceed the average values of other EU countries.

Moreover, other factors must be considered during the analysis, such as, for example, the urban-built environment that considerably influences the nation's greenhouse gas emissions. Therefore, encouraging urban development towards low-carbon outcomes helps to reduce carbon in the economy [23,24]. The urban areas present 60–80% of global energy use and are responsible for more than 70% of emissions [25].

The relationship between CO_2 emissions and tourism is also very little known; however, due to the development of international tourism, there is a threat that tourism may lead to environmental degeneration. Therefore, we plan to expand the scope of the research into CO_2 ratings according to the development of tourism by individual countries [26].

Mineral nitrogen presents an additional source of nitrogen for conversion to direct greenhouse gas emissions in the form of soil carbon losses [27]. In view of the above, the goal of the authors is to expand their future research by adding the assessment of waste, water, and carbon to the soil area.

The correlations between municipal solid waste and greenhouse gas emission must be considered as well, with a detailed examination of carbon emissions. This can be connected to the results of our research on waste [28]. It is also important to measure the volume of greenhouse gases or carbon footprint [29]. Future research could focus on designing energy-saving technology and an energy-saving campaign. In fact, there is little knowledge of the spatial heterogeneity of greenhouse gas emissions, especially in the field of agriculture [30]. Additional possible research can be orientated to green technology and sensible food practices, which can contribute to a reduction in emissions. Greenhouse gas emissions could also be assessed in terms of renewables and a regional approach in relation to economic growth and sustainability [31,32]. In particular, economic growth hinders sustainability due to greenhouse gas emissions.

6. Conclusions

The link between locally produced carbon emissions and climate change has long been proven by numerous scientific studies. Emission distribution can depend not only on climatic policy but also on the flexible mechanism orientated to providing effectiveness in achieving the emissions constraints [33,34].

A direct link between energy efficiency and productivity has also been proven, including the RES rate on overall energy mix of carbon emissions produced by the energy sector. The current geopolitical and energy situation is forcing EU countries to take strict measures aimed at:

- diversification of energy sources,
- increasing the efficiency of energy production,
- increasing the share of RES in the overall energy mix,
- reducing carbon emissions,
- reducing energy poverty.

These indicators, which have been monitored for a long time within the EU, have been thoroughly analyzed in order to find links among them. Analyses have shown that increased energy taxes can lead to increased energy efficiency, production, and a reduction in carbon emissions. The results of the analyses show that most EU countries are meeting the indicators set at the agreed level and are trying to gradually increase the share of RES in the overall energy mix. On the other hand, there are countries such as Norway, which have found a way to eliminate its dependence on imports of energy raw materials. Norway, despite its own sufficient oil resources, covers 70% of the renewable energy mix. In this way, it has the highest RES, even without an enormous increase in energy taxes. The result is a minimum level of energy poverty in the country.

The results show that EU countries also need to switch from fossil fuel and other non-renewable energy consumption to renewable energy sources in order to achieve carbon neutrality [35–38]. The results can also be used to ensure the environmental sustainability of the EU. The research is limited to the single evaluation of greenhouse gas emission; the goal of the authors for future research is to evaluate the soil use efficiency, as the next energy source. Moreover, future research includes a comparison of similar studies, as well as the use of various carbon emission accounting methods for robustness testing.

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