Economic performance and energy management – cross-sectional analysis and comparison for EU27 member states

Viktória Erőss
(corresponding author)
Budapest University of Technology and Economics, Faculty of Economic and Social Sciences, Department of Environmental Economics and Sustainability, Hungary
Email: viktoria.eross@edu.bme.hu

Imre Dobos
Budapest University of Technology and Economics, Faculty of Economic and Social Sciences, Department of Economics, Hungary

Tamás Pálvölgyi
Ludovika University of Public Services, Faculty of Water Sciences, Department of Water and Environment Policies, Hungary

The European Union's climate neutrality ambitions pose significant challenges for member states in terms of energy production, consumption and greenhouse gas emissions. The 2030 targets set out packages of measures that provide both a justification and a timely opportunity to explore the relationship between economic performance and certain indicators of energy management, with a view to answering the question of how the relationship between the different variables has evolved over time: have we seen a structural change or is the change more gradual? To this end, the present study examines the relationship between the relevant indicators (GDP, energy production/use, greenhouse gas emissions) of the 27 EU member states using multivariate statistical methods for the year 2012 and compares it with data from an analysis already carried out for the year 2022 (Erőss et al. 2025). In addition to presenting the changes identified using descriptive statistical tools, the study will use correlation analysis to assess the relationship between the individual indicators and principal component analysis to identify the key factors that play a role in the evolution of each variable. Finally, the authors use cluster analysis to highlight the changes that have taken place over the 10 years, by showing the differences between the country groupings. The results of the research do not show significant structural changes in the relationships between the variables, but both descriptive statistical tests and correlation analysis yield favourable figures for energy consumption and GHG emissions, which are below those registered for growth in economic performance. The results of the cluster analysis from 2012 to 2022 show a strengthening of the convergence of the member states based on the variables analysed.

Keywords:
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Introduction

Energy is a fundamental factor in everyday life and is now a prerequisite for social and economic development (Kashour 2023a). While life without energy is inconceivable (Bhuiyan et al. 2022), the greenhouse gases emitted into the atmosphere through the use of fossil fuels for energy production are a major contributor to the adverse acceleration of the rate of climate change (Paraschiv–Paraschiv 2020). Popescu et al. (2018) also confirm the central and complex role of energy in societies through their research on EU member states, and emphasise its future importance in several dimensions (e.g. climate change, political stability, etc.).

Research shows that increases in human well-being increase energy use, but the strength of the relationship weakens as countries develop, i.e. the rate of increase in energy use lags behind the rate of increase in well-being at some point (Szép et al. 2022b).

Although empirical evidence is a positive sign of favourable trends, significant steps need to be taken to increase energy efficiency in the current decade, which is crucial given the accelerating pace of climate change. One of the key commitments made at the 28th UN Climate Change Conference (COP28) is to triple the global volume of renewable energy production by 2030, an undertaking that must be accompanied by further significant energy efficiency and GHG emission reduction commitments (COP28 2023).

As part of the international effort, the EU has made a binding commitment under the European Green Deal to become the world's first climate-neutral continent by 2050, with zero net greenhouse gas emissions. The climate policy measures to achieve this ambitious target set intermediate milestones for the EU and its member states. The European Commission's 'Fit for 55' package of measures aims to achieve a 55% reduction in GHG emissions by 2030 compared to 1990 levels (Szép et al. 2023), but also sets out further guidelines, for example on reforming the emissions trading scheme, increasing energy efficiency by 36% by 2030, or increasing the share of renewable energy to 40%. The REPowerEU plan, published in May 2022, conceived mainly as a response to the ongoing energy crisis, further emphasises the importance of increasing energy savings, diversified energy supply and clean energy production (EC 2022).

In 2023, the European Parliament and the Council tightened its previous target of 32% of the EU's gross energy consumption from renewable sources by 2030. Under the new energy policy objective set out in Directive 2023/2413, the target of 32% renewable share was increased first to 40% and then to 42.5%, adding that EU countries will aim to achieve 45% of renewable energy beyond the target (EP 2024). This target, given that the share of renewables in total energy consumption in 2022 was around 23% for the EU27 (EPRS 2024) (see in Appendix Figure A1), is a major challenge for member states. This justifies a cross-sectional analysis of economic and environmental indicators to explore how their relationships have changed over the last 10 years.

Ozturk et al. (2020) have collected the conclusions of a number of studies, the results of which vary depending on the methodology used to establish the direction of causality between energy consumption and economic performance (Ozturk et al. 2010). These findings are supported by the literature review of Shabhaz et al. (2017): while some studies suggest that energy consumption leads to economic growth, others support the opposite, and still others find evidence of a two-way causal relationship or even independence of these variables. Based on the above, the evolution of the relationship between the variables examined in this study cannot be taken for granted, which justifies and necessitates the ex-post analysis of the realised facts, thus contributing to effective management and regulation with new empirical results.

Kashour's (2023b) research on the relationship between household energy consumption and GDP in EU member states finds that fluctuations in GDP are the main cause of inequalities in energy consumption, and that while the average contribution of GDP to household energy consumption is almost negligible in the most developed countries, it is much larger in the less developed countries (Kashour 2023a). Bianco et al. (2019) show the same result, replacing household energy consumption by total energy consumption and GHG emissions, which are at the heart of the EU's energy strategy, while pointing out that knowing how individual member states contribute to the EU's goals is essential to achieve them, as it is the only way to make energy policies more targeted and effective (Bianco et al. 2019).

There is also a two-way relationship between GHG emissions and GDP: while more developed countries tend to experience a steady improvement in the energy intensity of economic growth, in other regions GDP and emissions remain highly correlated (Singh 2024).

While improving economic performance is a priority among government economic policy objectives, an attainment which in many cases leads to increased environmental pressures, a stable economic/financial background also ensures greater environmental mainstreaming (Guo et al. 2024) and helps to secure the financial base necessary to implement the economic aspects of the just energy transition (McCauley et al. 2023).

Given the need for unified EU action to achieve the global climate goals and the diverging performance of member states in relation to specific target areas, this study examines how the relationship between selected economic and environmental indicators has changed over a longer period of time between 2012 and 2022, an undertaking which provides an opportunity to detect meaningful structural changes and shifts. While for decades the respective community and government policies have been aimed at improving the areas of focus of this study (in particular energy management and climate change), the structural changes (or lack thereof) achieved in this way are mostly based on independent results of mapping the relationship between a single variable (GDP and energy consumption or GDP and GHG emissions). In contrast, the present study uses a broader set of indicators than hitherto, and applies sound and generally accepted methodological procedures, thus taking a decisive step towards narrowing the Practical Knowledge Gap in this area, as pointed out by Lennart (2023).

Given the unity of EU action to achieve global climate goals and the different performances of member states in relation to specific target areas, this study examines how the relationship between selected economic and environmental indicators has changed over a longer period (2012 to 2022) that allows for the detection of structural changes.

The main objective of the research is to explore the relationship between GDP and renewable energy production, energy consumption by sector, energy dependence and greenhouse gas emissions, and to identify the change in the relationship between the two over the period under study.

The research will first examine the changes in the values of the selected indicators from 2012 to 2022 using descriptive statistical methods in the light of climate commitments and national energy policy efforts, and then seek answers to the questions and results of the correlation analysis as set out in Table 1.

Table 1

The aims and expectations of the research

Research question	Expectations	Objective to be achieved by expectations
How will the relationship between GDP and renewable energy use change from 2012 to 2022?	Increasing positive correlation	Increasing use of renewables
How will the relationship between GDP and energy imports change from 2012 to 2022?	Weakening positive or strengthening negative correlation	Reduction of energy import dependence
How will the relationship between GDP and energy use change from 2012 to 2022?		Increase in energy efficiency
How will the relationship between GHG emissions and renewable energy sources change from 2012 to 2022?	Strengthening positive correlation	Reduction of GHG emissions

A further aim of the research is to find the answer to the questions of what background variables can be identified in the development of the variables under investigation in the two periods under study, as well as how can the EU member states be grouped according to the variables, and what conclusions can be drawn from the changes?

The research covers the member states of the European Union and uses empirical data and multivariate statistical analysis to investigate the evolution and changes in the indicators and their interrelationships. To this end, in addition to GDP and GHG emissions, a number of indicators related to energy flows are used. The full range of input and output factors of energy flows is illustrated in Appendix Figure A2 to facilitate an overview of the relationship between them - production and imports as input indicators and energy use for energy, industry and domestic heating as output variables.

In the following, the sources of the data on which the research is based and the multivariate statistical methods used to analyse them are presented, followed by the results of the analyses. First, the 2012 and 2022 data are analysed using descriptive statistical methods, then the differences between the 2012 and 2022 data are studied by correlation analysis. This is followed by a principal component analysis of the two periods under study, and then a cluster analysis. Finally, the authors briefly summarise the results of the analyses carried out and the conclusions drawn.

Data set and methodology

The analysis was based on a multivariate data analysis extended to the European Union countries, which included population data, GDP, GHG emissions and some categories of energy flows (production, consumption) relevant for the present research. The variables included in the study, their units of measurement and the abbreviated names used in the analysis are summarised in Table 2 below.

Table 2

Abbreviations for variables used in the presentation of research results

Variable name	Definition of term	Unit of measurement	Short name
Primary production of energy	Extraction of energy products in a useable form from natural sources. [1]	TJ/1,000 people	PEP
Renewable energy production	Energy sources that replenish (or renew) themselves naturally. [2]	TJ/1,000 people	REP
Energy import	'Imports' refer to ultimate origin (the country in which the energy product was produced) for use in the country and 'exports' to the ultimate country of consumption of the produced energy product. Amounts are considered as imported or exported when they have crossed the political boundaries of the country, whether customs clearance has taken place or not. [3]	TJ/1,000 people	IMP
Energy export		TJ/1,000 people	EXP
Energy sector own energy use	The total energy consumed by end users, such as households, industry and agriculture. [4]	TJ/1,000 people	ESEU
Industrial energy consumption		TJ/1,000 people	IEC
Household heating energy consumption (climate-corrected data)		TJ/1,000 people	HHEC
GDP	Gross domestic product. [5]	million EUR/1,000 people	GDP
GHG-emission	A group of gases contributing to global warming and climate change. [6]	kt/1,000 people	GHG

The study covers the years 2012 and 2022. To compare the results of the correlation analysis, this study processes the data for 2012, and for 2022 only a climate correction adjustment was made to the relevant variable using data collection and analysis from an existing study (Erőss et al. 2025). For this reason, the tables showing the results of the specific indicator set and correlation analysis for 2022 are included in the Appendix (Table A3 and A4).

The choice of 2022 is justified by the fact that it is the most recent data available at the time of analysis, while the choice and analysis of 2012 is justified by the long-time interval between the two years (10 years), which provides the opportunity to identify and detect structural changes.

In addition, the 2012 data are less affected by the 2008 financial crisis than previous years, so 2012 is in this respect similar to 2022, which can be characterised as a period of recovery from the Covid crisis. Given that the community has 27 member states in 2022, the data of the 27 countries that will be members in 2022 have been examined for both years under consideration. The input data for the analysis are taken from Eurostat data collection and are presented in the Appendix Table A1.

Regarding the baseline data, it should be noted that for the year 2012, statistics on the amount of energy used by households for heating purposes by member country were not available, so the data were produced on the basis of the total household energy use by member country in 2012, and the 'household energy use for heating purposes/total household energy use' ratio by member country in 2022.

The amount of energy used by households for heating was climate-corrected according to the methodology recommended by Szép et al. (2022a). The climate correction was determined as the average of the cooling daylight factor data for the years 2012–2022 [13].

The methods to achieve the research objectives were conducted using Ms Excel and SPSS 27 software package as shown in Table 3.

Table 3

Methods used for each research objective

Research objective	Method used
Exploring the evolution of variables	Descriptive statistics
Exploring relationships between variables	Correlation analysis
Identification of background variables	Principal component analysis, VIF
Grouping of EU member states	Cluster analysis

Correlation was tested using Pearson correlation coefficients (Ezekiel–Fox 1970). In order to ensure the feasibility of Principal Component Analysis (Hair et al. 1998), the Kaiser–Meyer–Olkin (KMO) measure and Bartlet test were performed to verify the adequacy of the sample and model, and the number of variables included in the analysis was reduced using variance inflation factor (VIF) indicator to detect the level of multicollinearity. The results of principal component analysis were presented after applying rotation (varimax) method.

Cluster analysis was performed using hierarchical cluster analysis with between-groups linkage method.

Among the limitations of the analyses in this study, it is necessary to mention the impact of the energy crisis in 2022, and given that the analysis does not only calculate energy consumption of households, but also energy consumption of other sectors, which may also be affected by climate and temperature conditions, the analysis uses data without climate correction.

Results

For the year 2012, the analysis was conducted for 216 items in line with the analysis carried out for 2022. The original dataset for 2022 included 270 data items for 10 variables for 27 EU member states, but by removing redundant data, the actual dataset was reduced to 216 items – by omitting total energy consumption and household energy consumption data (Erőss et al. 2025), thus ensuring that the results for the two years can be compared without any data distortion.

Since the data values from the data collection (see in Appendix Table A1) showed a significant difference in magnitude (especially for population numbers, GDP), specific data per thousand inhabitants were calculated (see in Appendix Table A2) in order to avoid outliers distorting the results of the analytical methods used.

Examination of indicators for 2012 and 2022 using descriptive statistical methods

As an introduction to the statistical analyses, this subsection compares the 2012 and 2022 results using descriptive statistical methods. Table 4 illustrates the relationship between the 2012 and 2022 datasets in Appendix Table A2.

Table 4

Trends in correlation, standard deviation and mean values between 2012 and 2022 data

	PEP	REP	IMP	EXP	ESEU	IEC	HHEC	GHG	GDP
Correlation coefficient (r)	0.842	0.966	0.954	0.963	0.965	0.967	0.956	0.923	0.756
Coefficient of variation V_{2012}	0.75	0.96	0.68	1.45	0.55	0.68	0.43	0.70	0.52
Coefficient of variation V_{2022}	0.67	0.82	0.60	1.18	0.53	0.61	0.43	0.67	0.40
$Average_{2012}$	65.58	21.37	140.38	50.87	6.17	24.12	17.30	9.45	25.23
$Average_{2022}$	57.59	23.32	140.13	51.26	5.36	22.45	14.05	7.66	37.73

The results in Table 4 show that there is a high or very high correlation between the values of the indicators examined in 2012 and 2022. The positive linear correlation is lowest for GDP (0.756) and does not reach the strongest category for primary energy production (0.842), but reaches the highest value above 0.9 for the other cases. These results show that there is no significant difference between the values of the indicators examined for the two periods.

The coefficient of variation between the data of the factors under study shows a high degree of dispersion for most of the factors under study, i.e. a significant deviation of the individual values from the arithmetic mean (Ghauri–Gronhaug 2016). In 2012, only the energy use for heating in the household sector is slightly heterogeneous; in 2022, however, the relative dispersion for this variable is below 0.5 for GDP. The case of energy exports and renewable energy production stands out, with the largest dispersion among EU member states. It can also be observed that the dispersion decreases in all cases from 2012 to 2022, i.e. the data series for the individual variables tend towards stability and homogeneity, but there are also significant differences between the individual member states and variables.

Based on the averages of the 2012 and 2022 data considered, it can be observed that, while imports and exports remained basically unchanged, all indicators showed a positive trend: primary energy production, energy use in all segments and average GHG emissions decreased, while renewable energy production and average GDP increased significantly. The stagnation in energy imports is fundamentally negative, as the data do not show any significant downward trend in energy dependence.

Analysis of the interrelationships (correlations) between indicators

Correlation analysis was used to examine the relationship between the factors related to the research questions formulated in the first two years. The results for 2012 are shown in Table 5 and the results for 2022 are shown in Appendix Table A4. It can be seen that there is both a positive and a negative relationship between the results – these results can be explained by the context of the variables involved. Many of the variables are not randomly correlated, i.e. the correlation is considered significant: in 2012, the significance level is below 5% for 16 out of 32 cases examined, while for 2022, the significance level is below 5% for 12 out of 32 cases (the correlation level is defined as the value around 0.054, according to the mathematical rounding rule).

Table 5

Pearson correlation analysis results, 2012

		REP	IMP	EXP	ESEU	IEC	HHEC	GDP	GHG
PEP	Pearson correlation	**0.525****	0.103	**0.549****	**0.630****	**0.408***	**0.452***	0.112	–0.093
	Sig. (2-tailed)	0.005	0.609	0.003	<0.001	0.035	0.018	0.578	0.646
	N	27	27	27	27	27	27	27	27
REP	Pearson correlation		–0.075	0.038	0.280	**0.639****	0.471*	0.175	**–0.431***
	Sig. (2-tailed)		0.710	0.849	0.158	<0.001	0.013	0.382	0.025
	N		27	27	27	27	27	27	27
IMP	Pearson correlation			**0.690****	0.190	**0.470***	0.294	**0.644****	**0.605****
	Sig. (2-tailed)			<0.001	0.342	0.013	0.137	<0.001	<0.001
	N			27	27	27	27	27	27
EXP	Pearson correlation				**0.602***	0.230	0.185	0.211	0.157
	Sig. (2-tailed)				<0.001	0.249	0.357	0.291	0.435
	N				27	27	27	27	27
ESEU	Pearson correlation					0.372	0.252	–0.044	–0.167
	Sig. (2-tailed)					0.056	0.205	0.826	0.405
	N					27	27	27	27
IEC	Pearson correlation						**0.702****	**0.642****	0.131
	Sig. (2-tailed)						0<.001	<0.001	0.515
	N						27	27	27
HHEC	Pearson correlation							**0.569****	0.197
	Sig. (2-tailed)							0.002	0.324
	N							27	27
GDP	Pearson correlation								**0.557***

* Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2-tailed).

In 2012, the relationship between GDP and renewable energy production moved in one direction, but the correlation level was weak and insignificant. In 2022, the one-way movement is also typical, but the correlation of 0.092 indicates a negligible linear relationship between the two variables. All this suggests that the increase in the share of renewable energy production is significantly below the GDP growth rate, which can be interpreted as a fundamentally negative phenomenon.

Regarding the relationship between GDP and energy imports, in 2012 there is a strong (0.644) and significant relationship between the two variables, with energy imports increasing at a lower rate than GDP growth, but also clearly increasing. This suggests that from 2012 to 2022, the growth of energy imports is more likely to lag behind the growth of GDP, but it is also worth noting that, regardless of the significance of the results, the phenomenon in 2022 may be strongly linked to the energy crisis caused by the ongoing Ukrainian–Russian war and, by extension, to the phenomenon of shrinking energy import links. Although the change from 2012 to

2022, as shown by the correlation analysis, can be considered positive, it is at least partly the result of external pressures.

The negative relationship between industrial energy consumption and GDP is negligible (–0.044) in 2012, strengthening to a weak but secure relationship (–0.199) in 2022. If we set aside the lack of significance, the opposite direction of movement indicates a fundamentally positive correlation, as GDP growth is not associated with an increase in energy consumption in the energy sector, but rather a downward trend.

The strong level (0.642) and significance of the relationship between GDP and industrial consumption in 2012 is due to the strong correlation between GDP and industrial output, but the weakening of the relationship in 2022 (0.375), while still just significant (the mathematical rounding rules set the significance level at 5%, with a value of 0.054), is favourable. This suggests that as GDP grows, so does the increased use of more modern and efficient, energy-efficient industrial technologies, and also the increase in the weight of less energy-intensive sources of GDP (e.g. services sector).

The relationship between GDP and household sector energy use for heating in 2012 is moderately strong and significant (0.569), i.e. the two variables move together. This may be due to a number of factors, the most important of which are the general economic situation, changes in energy prices, changes in household income, investments in energy efficiency in the sector and housing conditions. Thus, although the evidence suggests that higher economic performance is not in principle associated with a reduction in household energy use for heating, further research may be needed to identify the factors and their effects. The result between the two variables moderates significantly in 2022: with a lack of significance, the relationship is 0.314, i.e. the significantly lower share of household energy consumption for heating compared to GDP growth is likely to be driven again by the energy crisis in 2022 and the resulting significant increase in natural gas prices.

In 2012, a medium significant correlation (–0.431) showed a lower but decreasing level of GHG emissions as the share of renewable energy production increases, but in 2022 this correlation loses strength and significance, with a correlation of only –0.120, which can be considered negligible.

Beyond the context of the research questions, the following should be noted:

- The relationship between primary energy production and renewable energy production in 2012 is moderately strong (0.525) and significant, indicating that a significant share of the growth in primary energy production in 2012 is through the use of energy from renewable sources. In 2022, the strength of the relationship increases (0.782) while maintaining significance.
- The use of renewable energy sources in all sectors (energy, industry, households) shows an increase (stronger correlation) from 2012 to 2022, which can be seen as a positive phenomenon supporting sustainable energy transition.

– There is a strong linear relationship between GDP and GHG emissions in both 2012 (0.557) and 2022 (0.551), and both relationships are significant. Although this is an understandable phenomenon due to the nature of the variables (GDP growth provides more opportunities for economic and social activities that generate GHG emissions), the direction of change from 2012 to 2022 can be seen as favourable.
– Energy imports show a strong significant relationship (0.690) with energy exports, partly due to movements in energy market prices and partly due to different regional needs and efforts to coordinate the available energy at a given time. The degree of the relationship strengthens in 2022 (0.773) and is also significant, with rising energy prices due to the energy crisis likely to play a key role.

Results of the principal component analysis

The main purpose of conducting principal component analysis was to identify background variables as well as hidden patterns based on the relationships between individual variables. Since strong correlations can be identified between several variables, this justified reducing the dimension of the data, while of course, retaining as much information as possible.

The values of the KMO measure (0.503 in 2012 and 0.576 in 2022) for both years raised the suspicion of multicollinearity, and so the variance inflation factor (VIF), which is based on a correlation matrix, was applied.

The VIF test for both 2012 datasets showed a strong multicollinearity between energy imports and energy exports, with a VIF of 19.605 for energy imports and 16.801 for energy exports, which resulted in a VIF of energy imports exceeding that of energy exports, but energy exports, which are less relevant to the research questions, were excluded from further analysis. As a consequence, all 2012 variables have a VIF value below 10. For the 2022 dataset, there was also a stronger relationship between energy exports and imports (import VIF of 6.838 and export VIF of 7.170), so in order to compare two datasets with identical variables, a VIF value above 5 (Vörösmarty–Dobos 2020) was not accepted for the 2022 data. By removing the energy export variable, the VIF of all 2022 variables remained below 5.

As a result of the test with the VIF indicator, the KMO of the two datasets was more favourable for the principal component analysis (2012: 0.630, 2022: .652).

As a result of the principal component analysis, it can be concluded that for both datasets, 2 principal components explain a significant proportion of the variables (70,0% in 2012, 64.6% in 2022).

To facilitate the interpretation of the results of the analysis, the components have been sorted (Table 6) using a varimax rotation procedure.

Table 6

Results of principal component analysis of the 2012 and 2022 dataset after varimax rotation

Variable 2012	Component		Variable 2022	Component	
	1	2		1	2
REP	**0.848**	–0.089	PEP	**0.890**	–0.125
PEP	**0.795**	0.022	REP	**0.882**	–0.041
IEC	**0.719**	0.552	IEC	**0.802**	0.368
ESEU	0.665	–0.043	HHEC	**0.722**	0.399
HHEC	<u>**0.636**</u>	<u>**0.515**</u>	ESEU	**0.602**	–0.181
GDP	0.197	**0.880**	GDP	0.054	**0.880**
IMP	0.057	**0.836**	GHG	0.054	**0.805**
GHG	–0.649	**0.819**	IMP	0.168	**0.520**

Notes: extraction method: principal component analysis; rotation method: varimax with Kaiser normalisation.

The results show that the majority of the variables are associated with the same principal component in both years.

In both years, GDP, energy imports and GHG emissions are linked to the same principal component, with consumption and fossil-based energy production being identified as influencing the background of these variables. Primary and renewable energy production and energy use in the energy sector are also linked to the same principal component in both years, with the correlation being the level of energy production.

In 2012, household energy use is almost equal for both principal components, and the result shows that both principal components are dominant in the evolution of the two variables. In 2022, however, the variable is clearly linked to the production principal component, which is understandably explained by the greater dependence on energy production than before as a consequence of the energy crisis in 2022. In other words, in 2022, the availability of energy will determine the level of consumption for the industrial and household sectors much more than consumption needs.

On this basis, the results of the principal component analysis can be illustrated as follows (Table 7).

Table 7
Determination of the main components of the variables under investigation

Variable 2012	Component		Variable 2022	Component	
	energy production	energy consumption and fossil energy production		energy production	energy consumption and fossil energy production
REP	**0.848**	–0.089	PEP	**0.890**	–0.125
PEP	**0.795**	0.022	REP	**0.882**	–0.041
IEC	**0.719**	0.552	IEC	**0.802**	0.368
ESEU	0.665	–0.043	HHEC	**0.722**	0.399
HHEC	<u>**0.636**</u>	<u>**0.515**</u>	ESEU	**0.602**	–0.181
GDP	0.197	**0.880**	GDP	0.054	**0.880**
IMP	0.057	**0.836**	GHG	0.054	**0.805**
GHG	–0.649	**0.819**	IMP	0.168	**0.520**

Results of the cluster analysis

Based on the cluster analysis carried out in the framework of the research, the EU member states were grouped according to the variables under study. The number of clusters was set at 5, in view of the fact that a smaller number of clusters would result in a larger proportion of EU countries being placed in the same cluster due to the outlier countries. Due to the lack of standardisation in the cluster analysis, the results of the between-groups linkage method are illustrated in Figure 1 and in Appendix Figure A3.

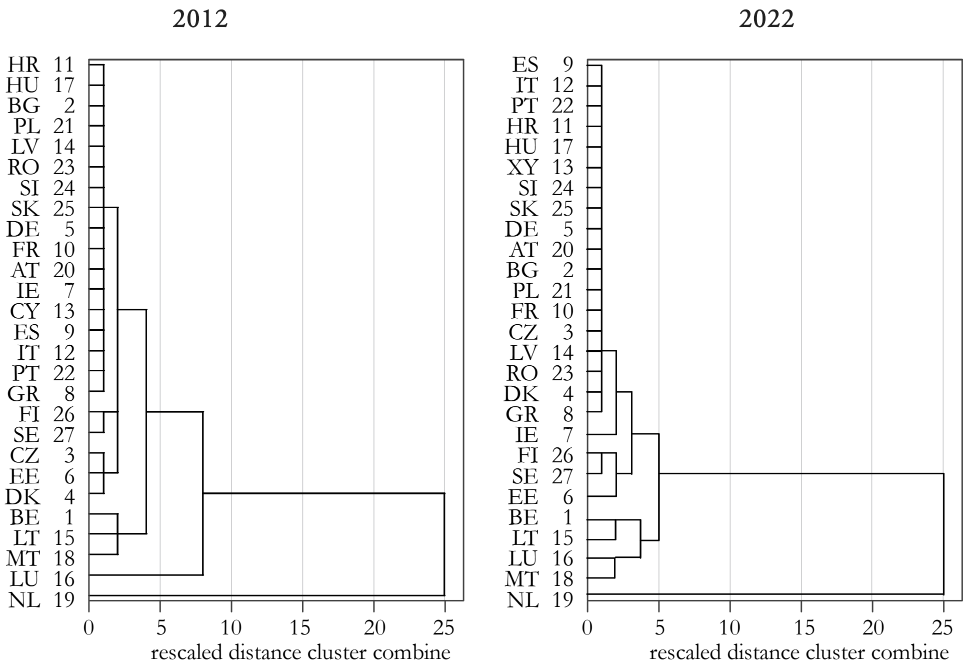
The results show that the cluster analyses for the two periods under review are largely similar, with only Malta and Denmark changing their cluster classification from 2012 to 2022; Malta moved from cluster 1 to cluster 4, while Denmark moved from cluster 3 to cluster 2, which includes most member countries.

Belgium and Lithuania in the first cluster share below average primary and renewable energy production in both years, with energy imports above average, while the other variables are largely around the EU average. Similarities in these characteristics can also be observed for Malta in 2012, based on the variables included in the analysis.

Most of the elements of the population (18 countries in 2012 and 19 in 2022) belong to the second cluster, which suggests that the data for the majority of EU member states examined are essentially homogeneous in both periods, and that the increase in the number of cluster members suggests the existence of a community energy policy. The difference between the two periods is found in cluster 2 in Denmark. This member state was clustered with Estonia, Finland and Sweden in 2012 due to its above-average primary energy production and above-average energy use in the energy and household sectors. In 2022, above-average energy use in the energy sector is no longer a common feature, and the two 2nd pillars are no longer clustered. The two countries in cluster two will also have primary energy production volumes closer to the average, but a decisive factor may be that the renewable energy production volumes of the other three countries will be further away from the average (in a positive direction), while Denmark will be around the EU average. Based on all these characteristics, Denmark shows more commonalities with cluster 2 members in 2022, while above average primary and renewable energy production and energy use in the energy industry and domestic heating still places Estonia, Finland and Sweden in a separate cluster (cluster 3).

Figure 1

2012 and 2022 dendrogrammes showing the results of the cluster analysis



Note: for country codes see Table A1 in Appendix.

Outlier countries are placed in clusters 4-5. In the case of Luxembourg, a significantly different (high) GDP, GHG emissions, energy imports and significantly below average primary and renewable energy production are the reasons for the significant deviation from the pattern, despite the fact that both primary and renewable energy production are expected to increase significantly by 2022. Based on the data included in the analysis, Malta will be placed in cluster 4 in 2022 due to its GDP doubling compared to 2012.

In the case of the Netherlands, energy imports in 2012, alongside the exceptionally high primary energy production, also show an exceptionally high value of energy imports and provide the basis for the country to be placed in a separate cluster. By 2022, although the value of primary energy production is already in line with the EU average, the unchanged value of the other two factors identifies the country as an outlier and places it in a separate cluster.

A better overview of the results and the common characteristics of each cluster is summarised in Table 8 below.

Table 8

Overview of cluster analysis results and common characteristics of clusters

Cluster serial number	Cluster members 2012	Change in cluster members compared to 2012	Common characteristics of cluster members (deviation from the mean of each variable)
1.	BE, LT, MT	–MT	Below average primary and renewable energy production, high energy imports
2.	AT, BG, CY, DE, ES, FR, GR, HR, HU, IE, IT, LV, PL, PT, RO, SI, SK,	+DK	Data close to the EU average compared to other clusters
3.	EE, CZ, DK, FI, SE	–DK	High primary and renewable energy production, household and energy use
4.	LU	+MT	High GDP, GHG emissions and energy imports, below average primary and renewable energy production
5.	NL	–	High primary energy production, energy imports and energy sector energy consumption

Note: for country codes see Table A1 in Appendix.

The results of the cluster analysis show that, based on the indicators of the EU member states studied, a smaller proportion of countries are more dispersed, resulting in 70% of countries being clustered together by 2022 (an increase of almost 4% compared to 2012). This situation is basically in line with the member states' efforts to comply with the community's energy policy guidelines, but is also naturally influenced by a number of national specificities (different energy cultures, differences in economic sectors, different shares of energy-intensive sectors, levels of urbanisation or differences in energy efficiency) which bias the cluster analysis in the same direction or even give them an outlier role. This is broadly in line with the member states' efforts to keep the community's energy policy guidelines in mind. In addition, for the countries that are outliers in both years, some of the outlier variables show values closer to the EU average from 2012 to 2022.

Conclusion

The present study examined the relationship between economic performance, energy production, and use, and GHG emissions variables for the years 2012 and 2022. The study aimed to compare the current (latest available, 2022) relationships with the results of previous years. The choice of 2012 was justified by the fact that, in addition to the period of approximate relief from the effects of the global financial crisis of 2009, the analysis of significantly distant periods reveals structural changes more clearly than in shorter periods.

The descriptive statistical analyses show that the correlation between the two periods is particularly strong, with significant variation in the dispersion of the variables by country, with a decrease in the range of variation from 2012 to 2022. The change in the average values of each variable shows mostly positive trends: the average values of primary energy production and energy use and GHG emissions by sector show a decrease, while the average values of renewable energy production and GDP show an increase. Imports remain stable, which does not support a positive reduction in energy dependence. All this suggests that, with the exception of energy imports, the figures under review have changed in the desired direction, i.e. the economic and energy policy efforts to achieve these goals can be considered successful in terms of the direction of change.

In the case of energy imports, however, the descriptive statistical analyses do not show a positive change in direction; in this area, further investigation at member state level is required to identify which countries show a stable or increasing dependence on energy imports and which may require policy interventions at national level to reduce the share of energy imports.

It is also worth mentioning the results of the analysis of the relationship between GDP and energy imports, which show a strong significant linear correlation between the two variables in both years, but a weakening of the relationship from 2012 to 2022. Thus, although imports are higher in the context of higher GDP, the share of imports is below the growth rate of output growth and the relationship weakens from 2012 to 2022, although the results for 2022 are likely to be affected by energy supply problems in that year. This also suggests that the unchanged energy dependency ratio at EU level is a negative outcome; further analysis at member state level is needed to identify which countries show unchanged or increasing energy import dependency and to identify policy interventions at national level that may be needed to reduce the share of energy imports. In addition, member states should pay attention to the need to source the additional energy needed for GDP growth from domestic renewable energy sources rather than imports.

Further results from the correlation analysis show that the relationship between GDP and renewable energy production does not provide sufficient evidence that the share of renewable production increases proportionally with higher economic output.

This result suggests that economic priorities are overemphasizing environmental and climate policy considerations. While the latter is a pressing issue, the share of renewables is rising at a much slower pace than economic output. In the light of these results, there is a strong case for considering better coordination of economic and climate policies at both EU and national level and for prioritising and mainstreaming climate ambitions.

The relationship between GDP and energy consumption for heating in the household sector shows that, although GDP growth does not seem to be driving household energy consumption of heating, the relationship between the two variables weakens from 2012 to 2022, again suggesting the impact of sharply rising energy prices due to the energy crisis.

The correlation analysis shows a weak relationship between GDP and industrial energy use in 2012 with a medium-strong correlation in 2022. This may be due to the modernisation and energy efficiency efforts of the consumer group concerned, as well as to the shift towards low energy-intensive service sectors. The weak negative correlation with energy use in the energy sector (but increasing from 2012 to 2022) also suggests technological progress and efficiency improvements in the energy sector, and the impact of the energy price collapse in 2022 due to the energy crisis may also be felt in this area. The result suggests that policies should continue to encourage energy efficiency improvements for specific user groups.

As regards the relationship between renewable energy production and GHG emissions, the data shows a negative relationship, i.e. GHG emissions decrease as renewable energy production increases, but the trend from 2012 to 2022 is negative, and the background of this phenomenon cannot be concluded from the data. Given the importance of the two variables and the relationship between them in national and EU energy and climate policies, it is essential to identify the factors that induce the results obtained, so that the necessary steps can be taken to move the relationship between the variables in a positive direction.

Based on the results of the principal component analysis, the evolution of the 9 variables under investigation can be attributed to 2 main background factors. It should be noted that household energy use in 2012 is linked to both principal components, but in 2022 the variables are clearly production-driven, with the energy crisis of the period likely to play a significant role. The results of the principal component analysis for energy use that needs to be optimised clearly point to the prominent role of energy prices, both as a direct influence on the amount of energy consumed and as a motivation for certain groups of consumers to become more energy efficient as a result of higher consumer prices.

The results of the cluster analysis, which become more homogeneous from 2012 to 2022, as well as the relative dispersion results, suggest the impact of community energy, environment and climate policies, which may warrant further investigation to identify the effects of these policies and the causes of outliers. In addition, re-cluster analyses could be the subject of further research once the outliers have been removed.

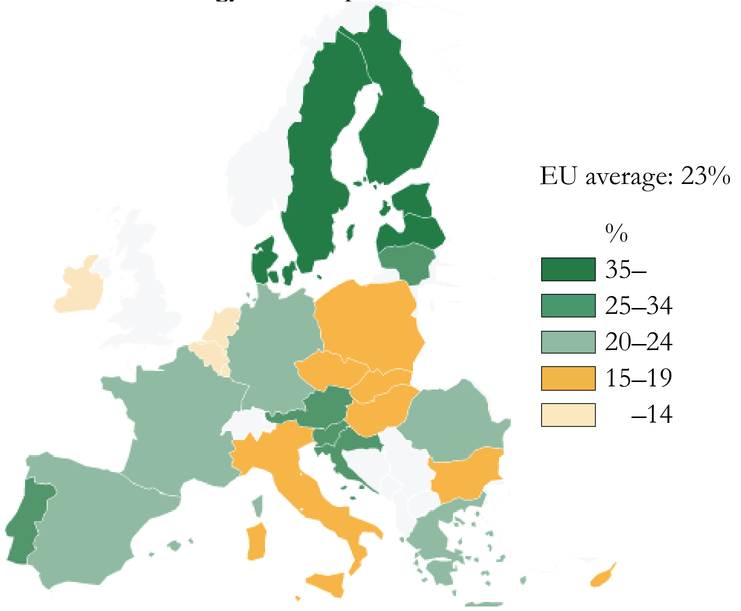
Overall, the results of the study do not show any structural change in the correlation between the two years of data examined. There were positive and negative changes between the results of the two periods for each of the variables examined, which allowed the research questions to be answered.

In several cases, the results of the correlations examined suggest the causality of an energy crisis in 2022, which would bias the relationship between the variables in a positive direction. It may therefore be useful to carry out further analyses focusing on this circumstance, in order to establish whether the forcing effects of certain exogenous sources may contribute more strongly to influencing certain processes in a positive direction (e.g. energy use in certain segments) than endogenous efforts, while the durability of these results may also need to be tested in the future (when the necessary data become available). A further research objective could also be to carry out a complex socio-economic impact assessment related to the achievement of a sustainable energy transition and the fulfilment of climate commitments, given the challenges in this area, and, partly due to the consequences of exogenous impacts and partly due to the sensitivity and topicality of the subject, it is also justified and useful to address the issue of energy poverty.

Appendix

Figure A1

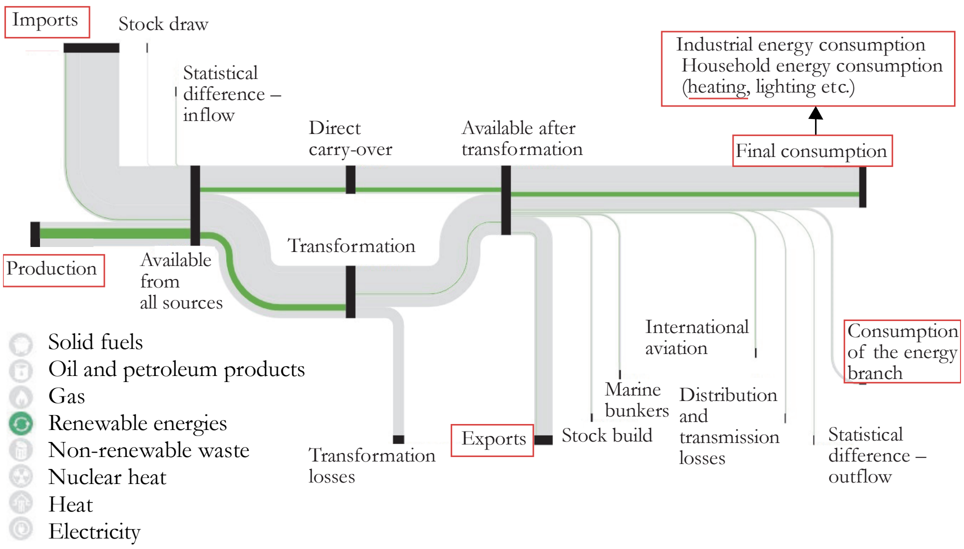
Share of energy from renewable sources
in final energy consumption – EU27, 2022



Source: own editing, based on EPRS (2024).

Figure A2

Energy flow – Sankey diagram



Source: [7].

Figure A3

Map of the cluster analysis results

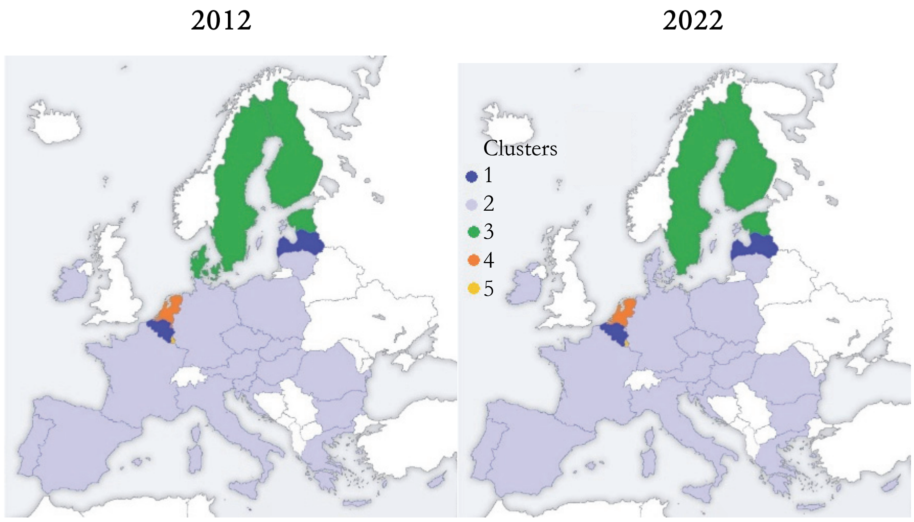


Table A1

Data for EU countries in 2012, the baseline for our analysis

Country code/name		Primer energy production	Renewable energy production	Energy import	Energy export	Energy sector own energy use
		TJ				
BE	Belgium	567,148	118,105	3,178,774	1,242,637	101,701
BG	Bulgaria	489,267	69,581	504,256	219,398	45,819
CZ	Czech Republic	1,355,184	158,954	822,886	362,793	106,840
DK	Denmark	790,061	128,889	661,237	686,076	49,973
DE	Germany	5,292,459	1,501,907	10,099,082	1,740,038	503,807
EE	Estonia	198,917	44,225	129,558	80,459	8,757
IE	Ireland	54,020	31,159	573,009	77,115	10,088
GR	Greece	438,621	97,306	1,353,954	539,855	79,371
ES	Spain	1,407,053	611,911	5,255,048	1,065,094	374,826
FR	France	5,729,619	959,292	6,684,214	1,292,650	295,039
HR	Croatia	177,222	82,000	286,945	104,771	27,132
IT	Italy	1,463,890	883,600	6,824,349	1,296,123	357,884
CY	Cyprus	4,739	4,739	110,818	0	655
LV	Latvia	97,836	97,610	174,684	61,875	3,439
LT	Lithuania	66,742	50,152	588,549	343,824	25,658
LU	Luxemburg	5,168	3,816	192,133	10,022	118
HU	Hungary	486,197	131,188	719,731	199,661	34,404
MT	Malta	368	368	91,927	345	439
NL	Netherland	2,767,021	167,111	7,583,380	6,372,127	219,961
AT	Austria	538,247	409,716	1,095,707	194,642	74,487
PL	Poland	2,976,762	357,368	1,982,803	685,927	258,168
PT	Portugal	197,149	191,036	942,276	178,223	44,689
RO	Romania	1,138,703	219,482	498,292	169,132	119,163
SI	Slovenia	146,117	44,526	217,515	65,332	4,645
SK	Slovakia	292,493	91,439	627,806	200,766	50,186
FI	Finland	705,771	416,018	1,018,807	342,384	63,856
SE	Sweden	1,489,731	809,421	1,352,792	690,939	65,844

(Table continues on the next page.)

(Continued.)

Country code/name		Industrial energy consumption	Household energy use for heating	GHG-emission (kilotonne)	Population (1,000 people)	GDP (million EUR)
		TJ				
BE	Belgium	441,054	253,812	144,315	11,076	386,175
BG	Bulgaria	107,457	46,263	52,268	7,327	42,255
CZ	Czech Republic	281,617	206,296	128,464	10,505	163,759
DK	Denmark	96,437	106,717	59,941	5,581	254,301
DE	Germany	2,374,458	1,638,452	931,468	80,328	2,745,310
EE	Estonia	23,624	29,591	19,846	1,325	17,917
IE	Ireland	73,854	73,598	65,206	4,589	176,894
GR	Greece	125,415	122,151	119,351	11,086	188,381
ES	Spain	841,870	256,666	345,428	46,818	1,031,104
FR	France	1,226,880	1,233,260	466,471	65,277	2,088,287
HR	Croatia	46,021	72,400	22,832	4,276	44,761
IT	Italy	1,128,288	968,399	481,911	60,105	1,624,359
CY	Cyprus	7,263	5,406	9,807	862	19,495
LV	Latvia	34,643	37,126	8,463	2,045	22,098
LT	Lithuania	44,872	43,696	11,502	3,004	33,410
LU	Luxemburg	29,020	16,255	12,558	525	46,526
HU	Hungary	133,240	192,023	57,279	9,932	100,248
MT	Malta	1,832	646	7,290	418	7,365
NL	Netherland	567,679	275,765	256,262	16,730	658,232
AT	Austria	320,399	191,750	76,603	8,408	318,653
PL	Poland	574,984	546,995	357,483	38,064	385,389
PT	Portugal	192,851	36,345	69,228	10,542	168,296
RO	Romania	282,536	209,030	91,388	20,096	139,320
SI	Slovenia	50,552	32,269	12,277	2,055	36,253
SK	Slovakia	135,393	82,794	36,406	5,404	73,649
FI	Finland	428,443	150,048	41,089	5,401	201,037
SE	Sweden	470,768	189,412	9,110	9,483	427,903

Source: own editing based on [8]–[12].

Table A2

Variables derived from the basic data in Table A1, 2012

Country code/name		Primer energy production	Renewable energy production	Energy import	Energy export	Energy sector own energy use
		TJ/ 1,000 people				
BE	Belgium	51.2	10.7	287.0	112.2	9.2
BG	Bulgaria	66.8	9.5	68.8	29.9	6.3
CZ	Czech Republic	129.0	15.1	78.3	34.5	10.2
DK	Denmark	141.6	23.1	118.5	122.9	9.0
DE	Germany	65.9	18.7	125.7	21.7	6.3
EE	Estonia	150.1	33.4	97.8	60.7	6.6
IE	Ireland	11.8	6.8	124.9	16.8	2.2
GR	Greece	39.6	8.8	122.1	48.7	7.2
ES	Spain	30.1	13.1	112.2	22.7	8.0
FR	France	87.8	14.7	102.4	19.8	4.5
HR	Croatia	41.4	19.2	67.1	24.5	6.3
IT	Italy	24.4	14.7	113.5	21.6	6.0
CY	Cyprus	5.5	5.5	128.6	0.0	0.8
LV	Latvia	47.8	47.7	85.4	30.3	1.7
LT	Lithuania	22.2	16.7	195.9	114.5	8.5
LU	Luxemburg	9.8	7.3	366.1	19.1	0.2
HU	Hungary	49.0	13.2	72.5	20.1	3.5
MT	Malta	0.9	0.9	220.2	0.8	1.1
NL	Netherland	165.4	10.0	453.3	380.9	13.1
AT	Austria	64.0	48.7	130.3	23.1	8.9
PL	Poland	78.2	9.4	52.1	18.0	6.8
PT	Portugal	18.7	18.1	89.4	16.9	4.2
RO	Romania	56.7	10.9	24.8	8.4	5.9
SI	Slovenia	71.1	21.7	105.8	31.8	2.3
SK	Slovakia	54.1	16.9	116.2	37.1	9.3
FI	Finland	130.7	77.0	188.6	63.4	11.8
SE	Sweden	157.1	85.4	142.7	72.9	6.9

(Table continues on the next page.)

(Continued.)

Country code/name		Industrial energy consumption	Climate-corrected energy use for heating in households	GDP (million EUR/ 1,000 people)	GHG-emission (kt/ 1,000 people)
		TJ/ 1,000 people			
BE	Belgium	39.8	24.4	34.9	13.0
BG	Bulgaria	14.7	6.9	5.8	7.1
CZ	Czech Republic	26.8	20.9	15.6	12.2
DK	Denmark	17.3	21.0	45.6	10.7
DE	Germany	29.6	21.9	34.2	11.6
EE	Estonia	17.8	25.0	13.5	15.0
IE	Ireland	16.1	16.8	38.5	14.2
GR	Greece	11.3	12.1	17.0	10.8
ES	Spain	18.0	6.1	22.0	7.4
FR	France	18.8	20.2	32.0	7.1
HR	Croatia	10.8	18.1	10.5	5.3
IT	Italy	18.8	17.4	27.0	8.0
CY	Cyprus	8.4	7.7	22.6	11.4
LV	Latvia	16.9	20.1	10.8	4.1
LT	Lithuania	14.9	15.9	11.1	3.8
LU	Luxemburg	55.3	31.9	88.6	23.9
HU	Hungary	13.4	20.6	10.1	5.8
MT	Malta	4.4	2.2	17.6	17.5
NL	Netherland	33.9	17.9	39.3	15.3
AT	Austria	38.1	24.0	37.9	9.1
PL	Poland	15.1	15.8	10.1	9.4
PT	Portugal	18.3	4.0	16.0	6.6
RO	Romania	14.1	11.4	6.9	4.5
SI	Slovenia	24.6	16.4	17.6	6.0
SK	Slovakia	25.1	16.3	13.6	6.7
FI	Finland	79.3	30.4	37.2	7.6
SE	Sweden	49.6	21.6	45.1	1.0

Source: own editing based on [8]–[12], [13].

Table A3

Variables derived, 2022

Country code/name		Primer energy production	Renewable energy production	Energy import	Energy export	Energy sector own energy use
		TJ/ 1,000 people				
BE	Belgium	57.2	15.4	296.0	136.3	7.8
BG	Bulgaria	80.5	17.1	78.8	34.2	7.0
CZ	Czech Republic	100.6	22.1	95.6	25.9	7.7
DK	Denmark	70.9	36.1	124.9	72.4	6.6
DE	Germany	48.9	24.8	117.2	19.4	5.8
EE	Estonia	147.5	60.3	85.2	75.2	5.2
IE	Ireland	25.9	14.0	110.4	13.5	1.7
GR	Greece	21.0	14.4	150.5	74.8	6.4
ES	Spain	31.7	17.8	112.0	27.9	7.2
FR	France	66.5	17.5	89.9	19.2	3.5
HR	Croatia	40.1	26.2	95.7	40.0	4.7
IT	Italy	24.6	18.6	108.0	23.5	5.3
CY	Cyprus	11.9	11.4	122.6	0.8	1.1
LV	Latvia	65.3	65.0	85.9	46.9	1.8
LT	Lithuania	30.6	27.3	212.5	133.7	8.5
LU	Luxemburg	21.1	18.4	237.7	11.0	0.1
HU	Hungary	45.9	15.0	87.8	16.3	4.2
MT	Malta	3.9	3.9	244.8	2.9	0.4
NL	Netherland	57.8	20.7	446.0	295.6	11.1
AT	Austria	56.6	48.4	131.9	19.3	7.2
PL	Poland	67.4	15.3	73.0	18.2	6.6
PT	Portugal	27.3	26.7	87.8	20.7	4.2
RO	Romania	48.9	12.6	36.8	14.3	4.1
SI	Slovenia	59.8	19.1	129.9	61.6	1.9
SK	Slovakia	52.0	16.7	125.9	36.8	7.7
FI	Finland	147.9	96.0	167.6	66.3	9.5
SE	Sweden	143.0	90.0	128.9	77.4	7.7

(Table continues on the next page.)

(Continued.)

Country code/name		Industrial energy consumption	Climate-corrected energy use for heating in households	GDP (million EUR/ 1,000 people)	GHG-emission (kt/ 1,000 people)
		TJ/ 1,000 people			
BE	Belgium	34.5	17.2	47.7	9.3
BG	Bulgaria	16.5	5.8	12.5	7.2
CZ	Czech Republic	26.3	19.3	26.3	11.6
DK	Denmark	16.9	15.9	64.8	7.5
DE	Germany	26.9	17.8	46.6	9.4
EE	Estonia	11.3	22.2	27.0	10.9
IE	Ireland	17.7	12.2	100.1	13.4
GR	Greece	10.3	10.0	19.8	7.3
ES	Spain	15.8	4.4	28.4	5.5
FR	France	15.6	13.8	38.9	5.8
HR	Croatia	12.2	16.1	17.7	5.5
IT	Italy	17.5	13.7	33.3	6.7
CY	Cyprus	11.6	6.5	30.7	10.3
LV	Latvia	20.2	16.4	20.5	8.3
LT	Lithuania	14.2	16.0	24.0	4.6
LU	Luxemburg	35.2	22.2	120.1	14.7
HU	Hungary	18.6	17.8	17.4	5.5
MT	Malta	5.9	2.3	33.5	5.1
NL	Netherland	29.2	11.4	54.5	9.6
AT	Austria	35.5	20.3	49.8	7.8
PL	Poland	17.1	14.6	17.8	9.4
PT	Portugal	18.2	3.3	23.4	5.3
RO	Romania	12.6	10.4	14.9	3.3
SI	Slovenia	23.5	12.4	27.1	7.4
SK	Slovakia	24.4	14.3	20.2	5.5
FI	Finland	73.6	27.6	48.2	9.3
SE	Sweden	44.7	15.5	53.7	0.6

Source: own editing based on [8]–[12], [13].

Table A4

Pearson correlation analysis results, 2022

		REP	IMP	EXP	ESEU	IEC	HHEC	GDP	GHG
PEP	Pearson correlation	**0.782****	–0.145	0.201	0.461*	**0.565****	**0.556****	–0.059	–0.023
	Sig. (2-tailed)	0.000	0.472	0.316	0.016	0.002	0.003	0.771	0.909
	N	27	27	27	27	27	27	27	27
REP	Pearson correlation		–0.086	0.145	0.308	**0.675****	**0.536****	0.091	–0.119
	Sig. (2-tailed)		0.670	0.470	0.118	0.000	0.004	0.651	0.556
	N		27	27	27	27	27	27	27
IMP	Pearson correlation			**0.773****	0.288	0.264	0.047	0.386*	0.213
	Sig. (2-tailed)			0.000	0.145	0.184	0.816	0.046	0.286
	N			27	27	27	27	27	27
EXP	Pearson correlation				**0.610****	0.212	0.117	0.066	0.009
	Sig. (2-tailed)				0.001	0.288	0.562	0.743	0.964
	N				27	27	27	27	27
ESEU	Pearson correlation					0.416*	0.258	–0.203	–0.197
	Sig. (2-tailed)					0.031	0.194	0.309	0.325
	N					27	27	27	27
IEC	Pearson correlation						**0.633****	0.375	0.144
	Sig. (2-tailed)						0.000	0.054	0.473
	N						27	27	27
HHEC	Pearson correlation							0.353	0.376
	Sig. (2-tailed)							0.071	0.053
	N							27	27
GDP	Pearson correlation								**0.553****
	Sig. (2-tailed)								0.003
	N								27

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).
Source: own calculation – using SPSS 27 software.

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