POLITYKA ENERGETYCZNA – ENERGY POLICY JOURNAL

2026 ✦ Volume 29 ✦ Issue 3 ✦ 5–28

DOI: 10.33223/epj/215083

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Evaluating primary energy consumption efficiency in European economies: a correlation-regression approach

ABSTRACT: The significance of primary energy in the context of European economies is well-established, underscoring the critical need for advancing the energy sector to foster national economic development in the countries under study. Key challenges in energy consumption are identified, including the uneven distribution of energy resources, specific logistical infrastructure constraints, and variations in resource utilization across nations. The necessity of assessing the efficiency of primary energy consumption in European countries is highlighted, with a focus not solely on individual national efficiencies but on the broader environmental context

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within which European states function. A correlation-regression analysis is employed to examine the interrelationships between different fuel consumption types (oil, natural gas, coal, nuclear fuel, hydropower, and renewable energy), facilitating the determination of connection densities and the development of linear models. A robust correlation is identified among three primary fuel types: oil, natural gas, and renewable energy. The analysis demonstrates the influence of oil consumption on both natural gas and renewable energy consumption, as well as the reciprocal effect of natural gas consumption on renewable energy utilization. To assess the efficiency of primary energy consumption, an evaluation utilizing the functioning environment method is conducted, with per capita primary energy consumption as the primary outcome indicator. The analysis reveals that per capita primary energy consumption is the most significant factor influencing energy consumption efficiency, as evidenced by empirical data from Finland, Norway, and Sweden.

Keywords: primary energy, energy consumption efficiency, fuel types, correlation-regression method, functioning environment analysis

Introduction

Energy consumption is a crucial factor in the development of modern economies, with energy resources playing a significant role in economic growth and stability. According to the International Energy Agency (IEA), global energy consumption increased by 1.3% in 2023, with developed economies such as those in Europe continuing to account for a substantial portion of this demand (IEA 2023). Ensuring sufficient energy resources is a critical governmental task, particularly given the uneven distribution of energy sources, which makes efficiency a key consideration. In Europe, for instance, more than 50% of energy needs are met through imports, primarily in the form of oil and natural gas (Eurostat 2023), exacerbating concerns about energy security and the need for more efficient consumption strategies.

Despite extensive research on energy efficiency, existing studies rarely assess primary energy consumption within a unified comparative framework that simultaneously captures both interdependencies among fuel types and cross-country efficiency patterns – a gap this study addresses.

The issue of efficient primary energy consumption is particularly pressing in Europe, where many developed countries rely heavily on imported fuels such as oil and natural gas. In contrast, certain countries, such as Norway and Russia, possess substantial domestic energy resources. Logistical pathways for fuel delivery from non-European countries to Europe have been established over decades, contributing to both the complexity and the cost of energy imports.

Efficiency in primary energy consumption in European countries should not be considered as the sum of each state's efficiency but as an overarching framework for primary energy consumption. This approach identifies trends for coordinated policies in fuel use, aiming to

enhance the performance of both the energy sector and national economies across a unified Europe. According to Eurostat (2023), energy efficiency in the European Union improved by 1.7% on average between 2022 and 2023, yet disparities remain among member states, indicating the need for targeted improvements.

1. Literature review

The efficient use of primary energy has been widely examined within the broader context of modern economic and environmental challenges. Numerous studies highlight that traditional non-renewable energy sources – oil, natural gas, and coal – have historically been fundamental drivers of economic development (Farrell 1957). However, disparities in resource distribution across European countries continue to shape consumption patterns and national policy decisions (Pryshliak et al. 2022a). Countries with abundant domestic resources often exert influence on regional energy markets, whereas countries with high import dependency face heightened vulnerabilities (Pryshliak et al. 2021).

Recent research has also emphasized the importance of ensuring national energy security through diversification strategies and the introduction of bioenergy technologies. For instance, Hontaruk et al. (2024) demonstrated that biogas and digestate production may simultaneously enhance energy and food security – an approach applicable in broader European energy diversification strategies.

The transition toward renewable energy has gained increasing momentum due to environmental concerns and the finite nature of fossil fuel reserves (Energy Institute 2024). While renewable sources offer substantial ecological advantages, their integration into existing energy systems remains challenging, partly due to intermittency and limited secondary resource generation.

Bioenergy represents one of the most promising renewable sectors. Studies highlight the economic, technological, and ecological potential of biofuel production, particularly in agricultural and processing industries (Kaletnik et al. 2022; Pryshliak et al. 2021). Empirical findings indicate that resource utilization efficiency in agro-processing significantly influences the sustainability of biogas production systems (Koval et al. 2025). Furthermore, innovations in feedstock processing – such as improved homogeneity of dispersed mixtures – contribute to higher biofuel conversion efficiency, as shown in Polievoda et al. (2022).

The managerial and organizational aspects of sustainable energy production have also been explored. Varaksina et al. (2022) emphasized the importance of effective entrepreneurial systems for organic and renewable resource production under conditions of globalization and innovation-driven economic change.

Recent analytical studies reveal strong interdependencies between various energy carriers. According to the Energy Institute (2024), correlation-regression analysis identifies statistically

significant relationships between oil consumption and renewable energy development, as well as between natural gas use and renewable energy consumption. These dynamics highlight that the transition from fossil to renewable sources is not linear but interconnected with broader shifts in consumption structure.

Efficiency metrics, particularly per capita primary energy consumption, remain essential indicators for cross-country comparisons (Farrell 1957). Scandinavian countries – Finland, Norway, Sweden – consistently demonstrate superior efficiency due to diversified energy portfolios and advanced energy technologies (Pryshliak et al. 2022). Nonetheless, significant regional disparities persist across Europe, underscoring the need for harmonized policy design, targeted investments, and coordinated infrastructure development.

Regulatory differences between countries significantly influence biofuel market development and the pace of renewable energy adoption (Kaletnik et al. 2022). Coordinated policy efforts are essential to harmonize energy consumption patterns and achieve EU-wide sustainability targets. Moreover, the integration of biofuels into national energy strategies requires improvements not only in policy but also in technological, managerial, and marketing components.

Research by Lohosha et al. (2023) shows that internal marketing and stakeholder interaction along the value chain play a crucial role in the successful implementation of biodiesel technologies in agricultural enterprises. Such approaches could strengthen renewable energy market competitiveness and encourage broader participation.

2. Research objective

This study seeks to provide a comprehensive evaluation of primary energy consumption efficiency across European countries. It aims to analyze the interplay between various fuel types, including oil, natural gas, coal, nuclear fuel, hydropower, and renewable energy, to identify patterns and dependencies that influence energy utilization. By employing advanced correlation-regression analysis, the research endeavors to quantify the relationships between different energy sources, offering insights into how traditional and renewable energy systems interact within the broader energy framework. Furthermore, the study integrates the functioning environment method to assess marginal efficiency, focusing on both individual fuel types and aggregated energy consumption metrics. This dual approach not only facilitates the identification of optimal fuel variations but also provides a nuanced understanding of regional disparities in energy efficiency, enabling the formulation of targeted strategies to enhance energy sustainability and economic development across Europe.

3. Methods and models

To comprehensively analyze the efficiency of primary energy consumption across European countries, this study employs a combination of correlation-regression analysis and the functioning environment method. The correlation-regression method is utilized to investigate the relationships between various fuel types, including oil, natural gas, coal, nuclear fuel, hydropower, and renewable energy. This approach facilitates the construction of linear models and quantifies the density of connections, shedding light on interdependencies among these energy sources.

Complementing this, the functioning environment analysis method is applied to calculate efficiency coefficients at the national level. This method focuses on critical fuel types – oil, natural gas, and renewable energy – and evaluates their contribution to overall energy efficiency. By integrating these methodologies, the study provides a robust framework for identifying patterns of energy consumption, assessing regional disparities, and offering actionable insights into optimizing energy systems within the context of European energy policies and sustainability goals.

4. Main findings

The significance of primary energy lies in its potential to be converted into secondary resources, meeting the economic needs of a nation economy. The availability of primary energy is both an economic and political issue due to the considerable inequality in the distribution of energy sources among countries and the volume consumed by their citizens. The political dimension involves efforts to utilize domestic energy sources located within a country's territory to influence the policies of other states through pricing mechanisms for essential products.

Primary energy includes traditional fuels classified as non-renewable resources: oil, natural gas, coal, peat, etc. These resources are the most widely consumed, with extraction and logistics processes developed over many years.

In recent years, there has been significant growth in renewable energy production, such as solar, wind, thermal, and hydropower. On the one hand, the advantages of renewable energy are clear – the absence of the need to replenish depleted resources, contributing to improved environmental conditions. On the other hand, challenges remain in transforming primary renewable energy to ensure stable secondary resource generation. Consequently, the long-declared policies of many European countries to transition to "green energy" have not been fully realized, leading to a return to the use of traditional fuels.

It is essential to study the efficiency of primary energy consumption using statistical indicators for each resource and on a per capita basis across European countries. This study examines the consumption of primary energy by fuel type during 2023, including oil, natural gas, coal, nuclear

fuel, hydropower, and renewable energy (European Commission 2023; International Energy Agency 2023).

Each type of fuel plays a unique role in meeting the needs of European consumers. Oil holds the most critical role in this process, with consumption at 28.33 EJ, which is 41.1% higher than natural gas consumption, 70.4% higher than coal, 76.7% higher than nuclear fuel, 78.9% higher than hydropower, and 58.1% higher than renewable energy (Eurostat 2023; IEA 2023).

Oil consumption is proposed as the most prioritized area for meeting the needs of European countries. Despite political statements advocating for reducing the share of this fuel, oil consumption in 2023 decreased by only 0.94% compared to 2022. Table 1 presents the correlation-regression models and correlation coefficients for European countries, illustrating the impact of oil consumption on the consumption of other fuel types.

Table 1. The results of the correlation-regression analysis of the impact of oil consumption on the consumption of other fuel types across European countries based on the 2023 data

Tabela 1. Wyniki analizy korelacyjno-regresyjnej wpływu zużycia ropy naftowej na zużycie innych rodzajów paliw w krajach europejskich na podstawie danych z 2023 r.

X	Y	Equation	Correlation coefficient
Oil consumption	Natural gas consumption	$y = 0{,}647x - 0{,}0801$	0,91
	Coal consumption	$y = 0{,}276x + 0{,}0435$	0,53
	Nuclear energy consumption	$y = 0{,}1722x + 0{,}2226$	0,29
	Hydropower consumption	$y = 0{,}0099x + 0{,}3173$	0,04
	Renewable energy consumption	$y = 0{,}4838x - 0{,}0879$	0,91

Source: calculated by the authors based on Statistical Review of World Energy 2023.

As the analysis results show, oil consumption has no significant impact on the consumption of hydropower and nuclear fuel, and has only a minor effect on coal consumption, as the correlation density (correlation coefficient) is negligible. However, a significant impact of oil consumption on natural gas consumption and renewable energy consumption is observed, since the correlation density (correlation coefficient) approaches one (0.91 for both cases) (Figs 1 and 2).

Thus, if oil consumption is excluded ($x = 0$), the shortfall in natural gas consumption will amount to 0.0801 EJ (Fig. 1). The minimum oil consumption by European countries should be 0.182 EJ. A similar calculation can be made for renewable energy consumption (Fig. 2). In this case, the minimum oil consumption by European countries should also be 0.182 EJ, with a shortfall in renewable energy consumption of 0.0879 EJ in the absence of oil consumption ($x = 0$).

The second most significant fuel after oil is natural gas. We will evaluate the equations obtained from the results of the correlation-regression analysis of the impact of natural gas consumption on the consumption of other fuel types across European countries based on the 2023 data (Table 2).

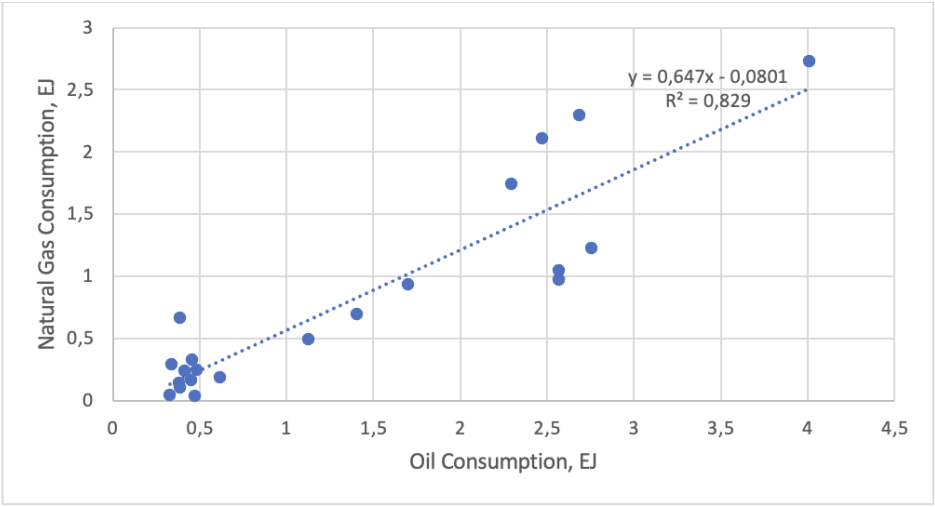


Fig. 1. The dependence of natural gas consumption on oil consumption
(calculated by the authors based on Statistical Review of World Energy 2023)

Rys. 1. Zależność zużycia gazu ziemnego od zużycia ropy naftowej

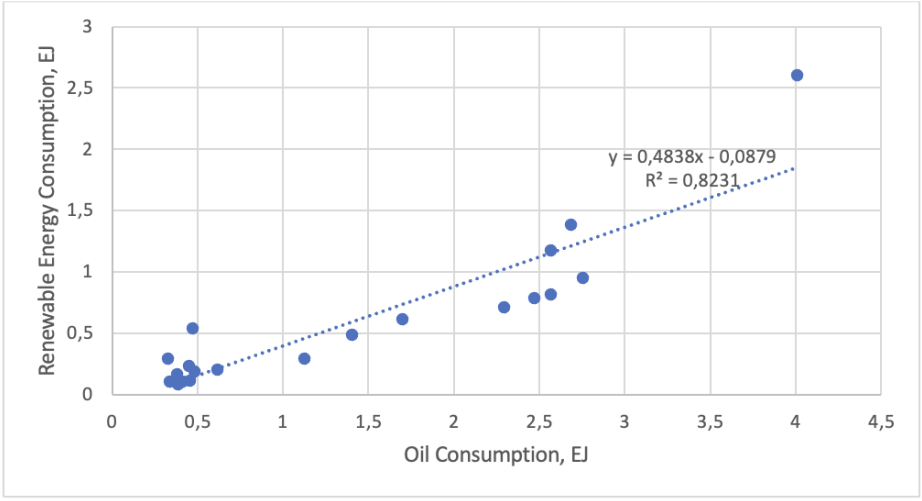


Fig. 2. The dependence of renewable energy consumption on oil consumption
(calculated by the authors based on Statistical Review of World Energy 2023)

Rys. 2. Zależność zużycia energii odnawialnej od zużycia ropy naftowej

A high correlation density (the correlation coefficient is 0.85) is observed in the case of the dependence of renewable energy consumption on natural gas consumption (Fig. 3). If European countries were to abandon natural gas consumption (x = 0), renewable energy consumption

Table 2. The results of the correlation-regression analysis of the impact of natural gas consumption on the consumption of other fuel types across European countries, based on the 2023 data

Tabela 2. Wyniki analizy korelacyjno-regresyjnej wpływu zużycia gazu ziemnego na zużycie innych paliw w krajach europejskich na podstawie danych z 2023 r.

X	Y	Equation	Correlation coefficient
Natural gas consumption	Coal consumption	$y = 0{,}3845x + 0{,}1113$	0,53
	Nuclear energy consumption	$y = 0{,}1045x + 0{,}3865$	0,11
	Hydropower consumption	$y = -0{,}0306x + 0{,}3565$	0,08
	Renewable energy consumption	$y = 0{,}6393x + 0{,}058$	0,85

Source: calculated by the authors based on Statistical Review of World Energy 2023.

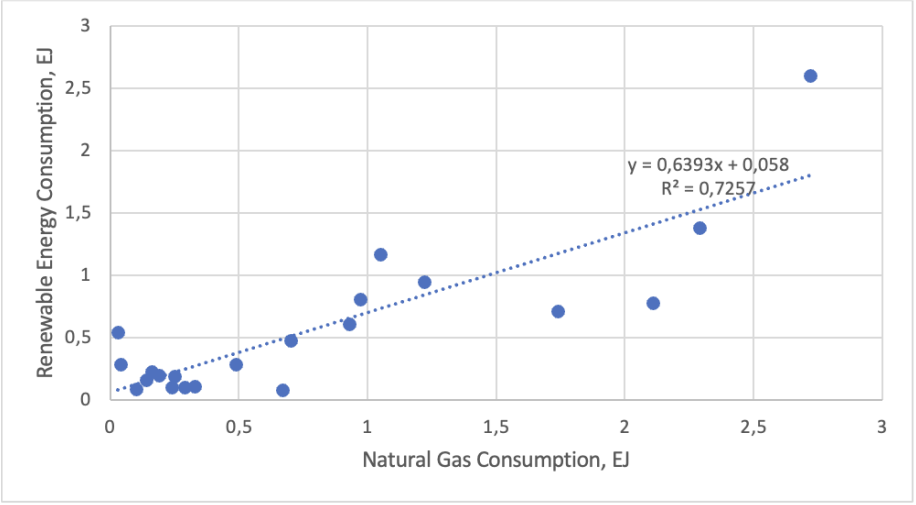


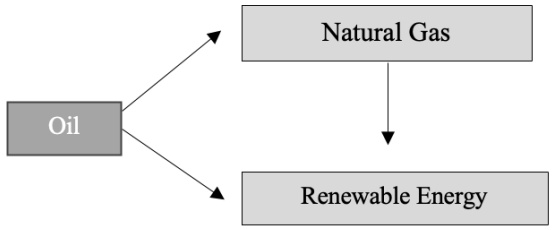
Fig. 3. The dependence of renewable energy consumption on natural gas consumption (calculated by the authors based on Statistical Review of World Energy 2023)

Rys. 3. Zależność zużycia energii odnawialnej od zużycia gazu ziemnego

would amount to 0.058 EJ. The use of natural gas stimulates the development of alternative energy sources, therefore there is currently significant interest in European countries in the supply of this fuel to meet the needs of both industry and ordinary consumers.

The results show that European countries are experiencing active circulation of different fuel types, with oil, natural gas and renewable energy sources playing a major role in energy consumption (Fig. 4).

For further research, we propose using the method of environmental functioning analysis, the essence of which lies in constructing a non-parametric model that allows for analyzing



Rys. 4. Directions of dependence for the three main types of fuel (constructed by the authors)

Rys. 4. Kierunki zależności dla trzech głównych rodzajów paliw

the level of efficiency in each European country. This method was proposed by M.J. Farrell (1957), who conducted research on natural monopolies based on the need to establish fair prices for their products. Since the late 1970s, the method of analyzing the operational environment has been employed by Charnes and Cooper (1994) as a scientific approach, particularly in the planning of production processes by multiplying the utilized resources by the final output. At present, various modifications of this method can be applied in the context of studied processes, including the determination of super-efficiency and sensitivity to changes in resource utilization (Zhu 2001).

In subsequent studies, the environmental functioning analysis method was used not only to evaluate the activities of natural monopolies but also in other sectors of economic activity, including the assessment of biofuels' efficiency in agriculture (Pryshliak et al. 2022b). Currently, this method is quite popular in studies of the activities of both enterprises and all sectors of the economy related to resource usage.

In our case, we propose using the indicators of primary energy consumption per capita in European countries (Y) as a performance indicator. The resource indicators are the consumption of oil (X_1), consumption of natural gas (X_2), and consumption of renewable energy (X_3).

The coefficients of the relationship between the volumes of oil, natural gas, and renewable energy consumption and the volume of primary energy consumption per capita in European countries can be grouped into three operational environments:

1) $X_1Y-X_2Y\frac{X_1}{Y}$ – $\frac{X_2}{Y}YX_1-YX_2$ (the ratio coefficient between the volume of oil consumption and the volume of primary energy consumption per capita in European countries) – (the ratio coefficient between the volume of natural gas consumption and the volume of primary energy consumption per capita in European countries);

2) $X_1Y-X3Y\frac{X1}{Y}$ – $\frac{X_3}{Y}YX_1-YX_3$ (the ratio coefficient between the volume of oil consumption and the volume of primary energy consumption per capita in European countries) – (the ratio coefficient between the volume of renewable energy consumption and the volume of primary energy consumption per capita in European countries);

3) $X_2Y-X_3Y\frac{X_2}{Y}$ – $\frac{X_3}{Y}YX_2-YX_3$ (the ratio coefficient between the volume of natural gas consumption and the volume of primary energy consumption per

capita in European countries) – (the ratio coefficient between the volume of renewable energy consumption and the volume of primary energy consumption per capita in European countries).

The indicators of primary energy consumption by fuel types (oil, natural gas, and renewable energy) are provided in Table 3.

Table 3. The indicators of primary energy consumption by fuel types (oil, natural gas, and renewable energy) and primary energy consumption per capita in European countries based on the results of 2023 [EJ] (Exajoules)

Tabela 3. Wskaźniki zużycia energii pierwotnej według rodzaju paliwa (ropa naftowa, gaz ziemny i energia odnawialna) oraz zużycie energii pierwotnej na mieszkańca w krajach europejskich na podstawie wyników z 2023 r. [EJ] (eksadżule)

No	Country	Y	X1	X2	X3
1	Austria	154.6	0.49	0.25	0.19
2	Belgium	197.8	1.13	0.49	0.29
3	Czech Republic	145.2	0.42	0.24	0.10
4	Finland	215.6	0.33	0.04	0.29
5	France	133.8	2.76	1.22	0.95
6	Germany	137.0	4.01	2.72	2.60
7	Greece	106.2	0.62	0.19	0.20
8	Hungary	89.7	0.34	0.29	0.10
9	Italy	101.0	2.47	2.11	0.78
10	Netherlands	195.0	1.70	0.93	0.61
11	Norway	363.7	0.38	0.14	0.16
12	Poland	100.3	1.41	0.70	0.48
13	Portugal	92.6	0.45	0.16	0.23
14	Romania	64.1	0.46	0.33	0.11
15	Spain	119.2	2.57	1.05	1.17
16	Sweden	202.7	0.47	0.03	0.54
17	Switzerland	128.8	0.39	0.10	0.09
18	Turkey	81.6	2.30	1.74	0.71
19	Ukraine	60.4	0.39	0.67	0.08
20	United Kingdom	102.6	2.69	2.29	1.38
21	Other European countries	108.6	2.57	0.97	0.81

Source: formed by the authors based on Statistical Review of World Energy 2023.

Analyzing Table 3, it can be concluded that the highest volume of primary energy consumption per capita in European countries for 2023 is observed in Norway. Followed by other Scandinavian countries – Finland and Sweden. The lowest volumes are observed in Ukraine, Romania, and Turkey.

In terms of oil consumption, Germany is the undisputed leader. Notably high consumption is also observed in France and the United Kingdom. The lowest consumption is seen in Finland, Hungary, and Norway.

In terms of natural gas consumption, the leaders are Germany, the United Kingdom, and Italy. The lowest consumption is observed in Sweden, Finland, and Switzerland.

In terms of renewable energy consumption, the leaders are Germany, the United Kingdom, and Spain. The lowest consumption is seen in Ukraine, Switzerland, Hungary, and the Czech Republic.

The best development option for a country is to increase the volume of consumption per capita while reducing the consumption of a specific type of fuel. Table 4 presents the calculation of the ratio coefficients for primary energy consumption by fuel types (oil, natural gas, and renewable energy) and primary energy consumption per capita in European countries based on the results of 2023.

Table 4. Calculation of the ratio coefficients for primary energy consumption by fuel types (oil, natural gas, and renewable energy) and primary energy consumption per capita in European countries based on the results of 2023

Tabela 4. Obliczenie współczynników ilorazowych zużycia energii pierwotnej według rodzajów paliw (ropa naftowa, gaz ziemny i energia odnawialna) oraz zużycia energii pierwotnej na mieszkańca w krajach europejskich na podstawie wyników z 2023 r.

№	Country	X1/Y	X2/Y	X3/Y
1	2	3	4	5
1	Austria	0.003	0.002	0.001
2	Belgium	0.006	0.002	0.001
3	Czech Republic	0.003	0.002	0.0007
4	Finland	0.0015	0.0002	0.001
5	France	0.021	0.009	0.007
6	Germany	0.03	0.02	0.02
7	Greece	0.006	0.002	0.002
8	Hungary	0.004	0.003	0.001
9	Italy	0.02	0.02	0.008
10	Netherlands	0.009	0.005	0.003
11	Norway	0.001	0.0004	0.0004
12	Poland	0.01	0.007	0.005

1	2	3	4	5
13	Portugal	0.005	0.002	0.002
14	Romania	0.007	0.005	0.002
15	Spain	0.02	0.009	0.01
16	Sweden	0.002	0.0001	0.003
17	Switzerland	0.003	0.0008	0.0007
18	Turkey	0.03	0.02	0.009
19	Ukraine	0.006	0.01	0.001
20	United Kingdom	0.03	0.02	0.01
21	Other European countries	0.02	0.009	0.007

Source: calculated based on the results of Table 3.

Based on the ratio coefficient between oil consumption and primary energy consumption per capita in European countries (X_1/Y), the highest values are observed in Germany, Turkey, and the United Kingdom. The lowest coefficient is seen in Finland, Norway, and Sweden.

For the ratio coefficient between natural gas consumption and primary energy consumption per capita in European countries (X_2/Y), the highest values are observed in Germany, Italy, Turkey, and the United Kingdom. The lowest coefficient is found in Finland, Norway, Sweden, and Switzerland.

For the ratio coefficient between renewable energy consumption and primary energy consumption per capita in European countries (X_3/Y), the highest values are observed in Germany, Spain, and the United Kingdom. The lowest coefficient is found in the Czech Republic, Norway, and Switzerland.

The application of the environmental functioning analysis method makes it possible to analyze the consumption of oil and natural gas in the context of increasing primary energy consumption per capita in European countries based on the results of 2023 (Fig. 5).

Each position in the figure corresponds to the number shown in Table 4. For example, position 19 belongs to Ukraine, and positions 6, 18, and 20 correspond to Germany, Turkey, and the United Kingdom, respectively, since their coordinates match.

The efficiency line is the line that connects the closest positions to the abscissa and ordinate axes. In our case, such positions are 4 (Finland) – 11 (Norway) – 16 (Sweden). This line indicates that, among all European countries based on the results of 2023, these countries have the most acceptable levels of oil and natural gas consumption in relation to primary energy consumption per capita.

All other countries can evaluate the level of efficiency of primary energy consumption relative to the line 4–11–16. The closer a European country's position is to the efficiency line, the more efficient its primary energy consumption is. Even visually, it can be determined that Switzerland

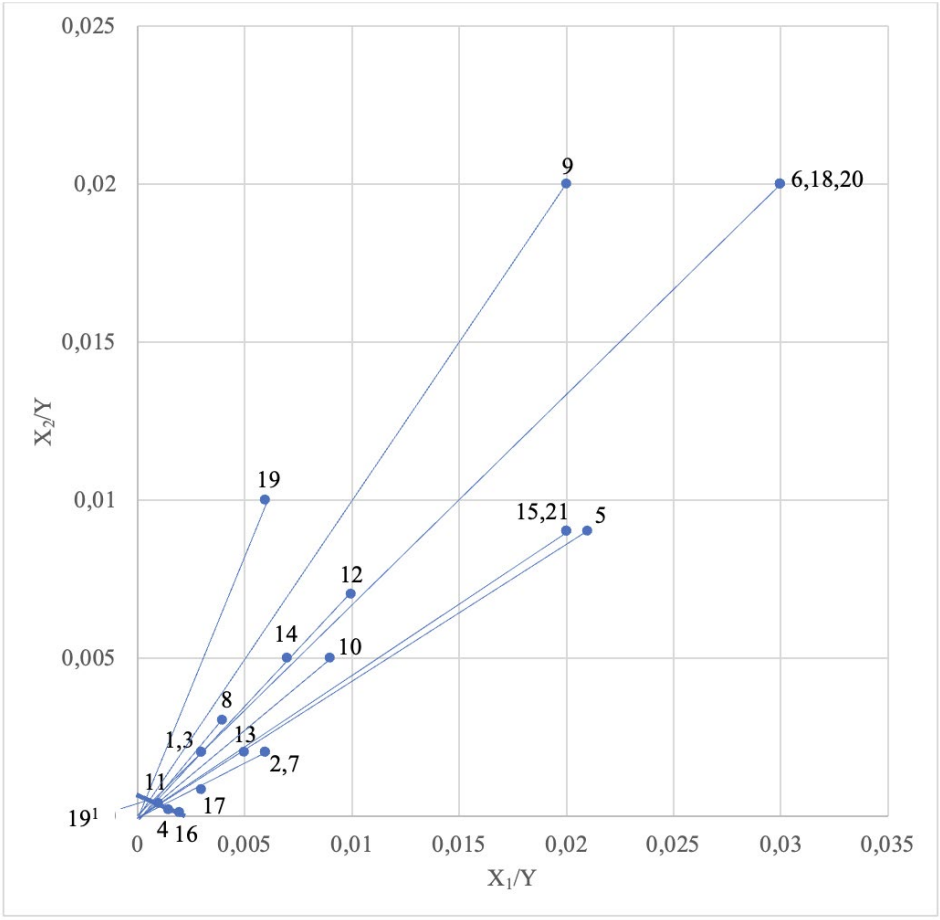


Fig. 5. Analysis of oil and natural gas consumption in the context of increasing primary energy consumption per capita in European countries based on the results of 2023 (calculated based on the results of Table 4)

Rys. 5. Analiza zużycia ropy naftowej i gazu ziemnego w kontekście rosnącego zużycia energii pierwotnej na mieszkańca w krajach europejskich na podstawie wyników z 2023 r.

consumes primary energy most efficiently, while Germany, Hungary, and the United Kingdom consume it the least efficiently.

The efficiency coefficient for each position is calculated as the ratio between the distances (using Ukraine as an example): 0–191/0–19. For positions that lie on the efficiency line, the efficiency coefficient will equal one. For all other positions, the coefficient will range from 0 to 1.

Table 5 presents all the efficiency (inefficiency) coefficients for primary energy consumption across European countries for 2023.

The analysis results suggest that European countries show a predominant inefficiency in primary energy consumption. Compared to Finland, Norway, and Sweden, only Switzerland

Table 5. Efficiency (inefficiency) coefficients of primary energy consumption (oil, natural gas) across european countries in 2023

Tabela 5. Współczynniki efektywności (nieefektywności) zużycia energii pierwotnej (ropa naftowa, gaz ziemny) w krajach europejskich w 2023 r.

No	Country	Efficiency coefficient	Inefficiency coefficient
1	Austria	0.25	0.75
2	Belgium	0.2	0.8
3	Czech Republic	0.25	0.75
4	Finland	1	0
5	France	0.05	0.95
6	Germany	0.02	0.98
7	Greece	0.2	0.8
8	Hungary	0.18	0.82
9	Italy	0.03	0.97
10	Netherlands	0.09	0.91
11	Norway	1	0
12	Poland	0.07	0.93
13	Portugal	0.23	0.77
14	Romania	0.10	0.90
15	Spain	0.06	0.94
16	Sweden	1	0
17	Switzerland	0.42	0.58
18	Turkey	0.02	0.98
19	Ukraine	0.07	0.93
20	United Kingdom	0.02	0.98
21	Other European countries	3	X
Total		2.32	2.32

Source: calculated based on the results from Fig. 5.

meets 42% of the criteria for efficient per capita consumption of oil and natural gas. Furthermore, the overall efficiency coefficient across the studied countries is 2.32, while the countries represented on the efficiency line (Finland, Norway, and Sweden) have a coefficient of 3. This can be attributed to several advantages in Scandinavian countries, such as having domestic oil and natural gas reserves, diversified fuel sources, minimal reliance on fuel-dependent heavy industries, and programs supporting fuel technology development. In contrast, countries with

the highest inefficiencies (Germany, Italy, Turkey, and the UK) are heavily dependent on fuel imports (mainly oil and gas), and their industries rely on primary energy as a key component for maintaining product competitiveness.

It should be noted that this situation reflects the traditional priorities in the development of European economies – the Scandinavian approach focuses on ensuring energy consumption efficiency among the population within the framework of a resource-based energy sector development, while the Western European approach emphasizes production efficiency, where increasing oil and natural gas consumption is particularly important for saving on public needs.

Renewable energy is seen as a solution to many problems related to the scarcity or limited availability of natural resources in nearly all European countries. However, it has been proven that the consumption of renewable energy is linked to the consumption of natural resources (oil and gas). Therefore, we will use the environmental analysis method to assess the efficiency of renewable energy consumption (Fig. 6).

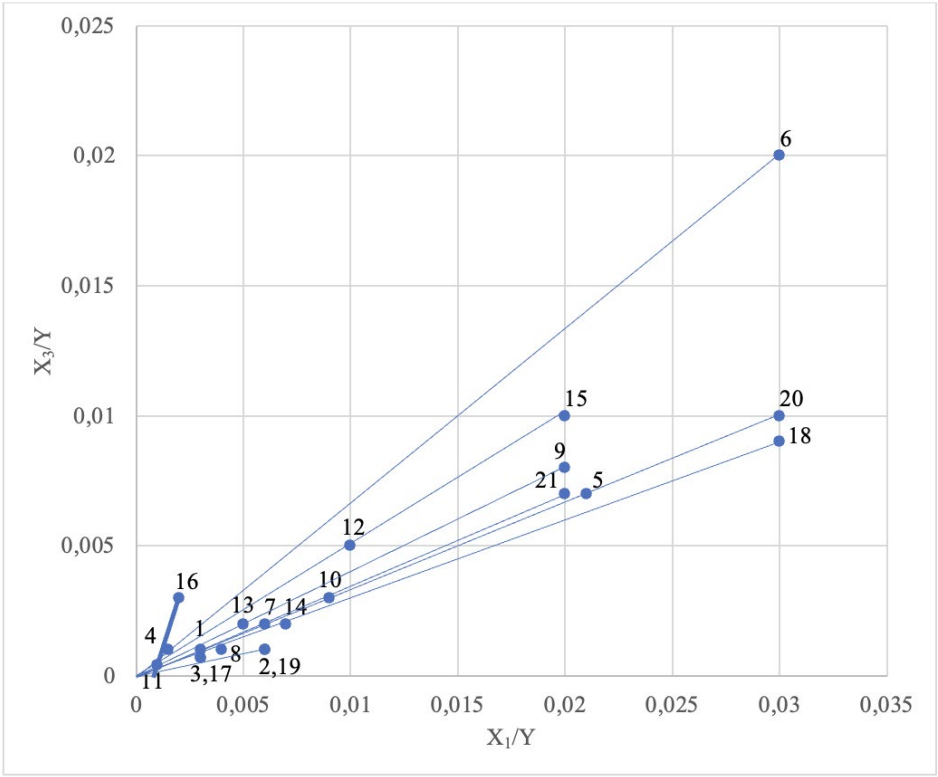


Fig. 6. Analysis of oil and renewable energy consumption in the context of increasing primary energy consumption per capita in European countries based on 2023 results (calculations based on the results from Table 4)

Rys. 6. Analiza zużycia ropy naftowej i energii odnawialnej w kontekście rosnącego zużycia energii pierwotnej na mieszkańca w krajach europejskich na podstawie wyników z 2023 r.

The same trend is observed as in the analysis of oil and natural gas consumption in relation to increased primary energy consumption per capita in European countries – the efficiency line is 4 (Finland) – 11 (Norway) – 16 (Sweden).

Table 6 presents the efficiency (inefficiency) coefficients of primary energy consumption (oil, renewable energy) for European countries in 2023.

Primary energy consumption (oil, renewable energy) in European countries is predominantly characterized by inefficiency. The most efficient countries in terms of primary energy consumption (oil and renewable energy) are the Czech Republic, Switzerland, Austria, and Hungary. The lowest efficiency is observed in Germany, Turkey, and the United Kingdom.

The overall efficiency coefficient for all countries (2.27) is lower than the total coefficient of 3 for the countries considered benchmarks in primary energy consumption (oil, renewable energy).

At first glance, comparing Figures 5 and 6 in the context of the obtained results, one might conclude that there is a certain similarity in the study's outcomes. Indeed, when it comes to the development of consumption trends for any type of energy, a certain uniformity is observed, which can easily be explained by the consumption models and economic development of the analyzed countries.

However, there are noticeable differences: firstly, the configuration of the efficiency line and the placement of countries along the efficiency line in Figure 6 differ significantly from those in Figure 5. Secondly, countries with inefficiency in oil and renewable energy consumption in the context of increasing primary energy consumption per capita in European countries, based on the 2023 results in Figure 6, can be divided into three groups according to the ratio coefficient between oil consumption and primary energy consumption per capita:

- **Group 1:** Austria, Belgium, Czech Republic, Greece, Hungary, Netherlands, Poland, Portugal, Romania, Switzerland, Ukraine.
- **Group 2:** France, Italy, Spain, and other European countries.
- **Group 3:** Germany, Turkey, United Kingdom.

This division is explained by the lower consumption of renewable energy compared to natural gas consumption, which primarily does not change the priorities of the most developed countries (Group 3), allows new opportunities to be formed for some (Group 2), and to some extent indicates an improvement in countries where industrial development is not the basis for achieving national economic efficiency.

Table 7 presents a comparison of natural gas and renewable energy consumption volumes for 2023 across European countries.

As shown in Table 7, the volume of consumed renewable energy is 4.82 EJ less than the volume of consumed natural gas. However, in some countries, more renewable energy has been consumed compared to natural gas. These countries include Finland, Greece, Norway, Portugal, Spain, and Sweden. It is important to note that all three positions making up the efficiency line are present among the listed countries, with two countries from the first group and one from the third. Therefore, we can conclude that the change in the efficiency line follows a pattern towards lower energy consumption efficiency for the population of these countries.

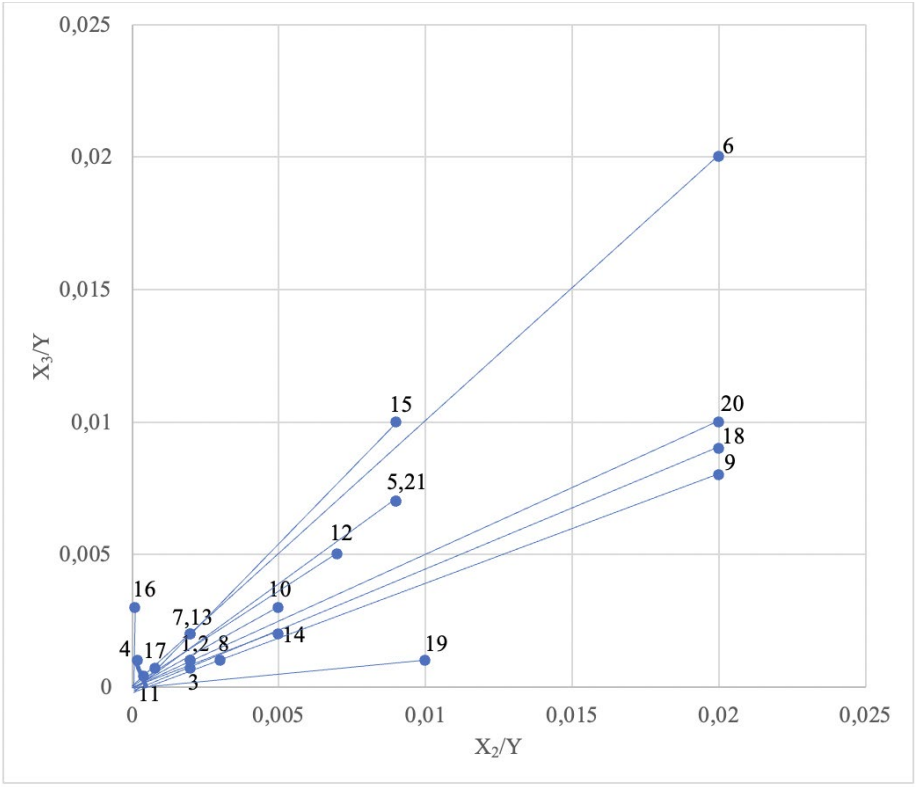
Table 7. Comparison of natural gas and renewable energy consumption volumes for 2023 across European countries [EJ]

Tabela 7. Porównanie zużycia gazu ziemnego i energii odnawialnej w 2023 r. w krajach europejskich [EJ]

No	Country	Volume of natural gas consumption	Volume of renewable energy consumption	Deviation (+;–)
1	Austria	0.25	0.19	–0.06
2	Belgium	0.49	0.29	–0.2
3	Czech Republic	0.24	0.10	–0.14
4	Finland	0.04	0.29	+0.25
5	France	1.22	0.95	–0.27
6	Germany	2.72	2.60	–0.12
7	Greece	0.19	0.20	+0.01
8	Hungary	0.29	0.10	–0.19
9	Italy	2.11	0.78	–1.33
10	Netherlands	0.93	0.61	–0.32
11	Norway	0.14	0.16	+0.02
12	Poland	0.70	0.48	–0.22
13	Portugal	0.16	0.23	+0.07
14	Romania	0.33	0.11	–0.22
15	Spain	1.05	1.17	+0.12
16	Sweden	0.03	0.54	+0.51
17	Switzerland	0.10	0.09	–0.01
18	Turkey	1.74	0.71	–1.03
19	Ukraine	0.67	0.08	–0.59
20	United Kingdom	2.29	1.38	–0.91
21	Other European countries	0.97	0.81	–0.16
Total		16.68	11.86	–4.82

Source: formed by the authors based on Statistical Review of World Energy 2023.

The analysis of natural gas and renewable energy consumption in the context of the increase in per capita primary energy consumption in European countries for the year 2023 (Fig. 7) confirms that the efficiency line consists of two positions: 4 (Finland) and 11 (Norway). Unlike other studies (Figs 5 and 6), position 16 (Sweden) is absent from the efficiency line. The reason for this is that, among all Scandinavian countries, Sweden has the highest consumption of renewable energy and the lowest volume of primary energy consumption per capita.



Rys. 7. Analysis of natural gas and renewable energy consumption in relation to the increase in per capita primary energy consumption across European countries for the year 2023 (calculated based on the data from Table 4)

Rys. 7. Analiza zużycia gazu ziemnego i energii odnawialnej w odniesieniu do wzrostu zużycia energii pierwotnej na mieszkańca w krajach europejskich w 2023 r.

Thus, the most efficient consumption of primary energy (natural gas, renewable energy) is observed in Switzerland. The highest levels of inefficiency are found in Germany, Italy, Turkey, and the United Kingdom.

Germany stands out as an undisputed leader in the consumption of oil, natural gas, and renewable energy; however, its per capita primary energy consumption is significantly lower compared to many other nations. A similar trend is observed in other leading European countries: France, the United Kingdom, Spain, and Italy have the highest oil consumption among all the countries studied, while the United Kingdom, Italy, and Turkey lead in natural gas consumption, and the United Kingdom, Spain, and France are at the forefront in renewable energy consumption. Based on the results obtained, it can be concluded that, during the studied period, the key factor in achieving efficiency in primary energy consumption (oil, natural gas, and renewable energy) is not so much the total volumes of consumption, but rather the per capita energy consumption.

Table 8. Efficiency (inefficiency) coefficients of primary energy consumption (natural gas, renewable energy) across european countries for the year 2023

Tabela 8. Współczynniki efektywności (nieefektywności) zużycia energii pierwotnej (gaz ziemny, energia odnawialna) w krajach europejskich w 2023 r.

No	Country	Efficiency Coefficient	Inefficiency Coefficient
1	Austria	0.25	0.75
2	Belgium	0.25	0.75
3	Czech Republic	0.27	0.73
4	Finland	1	0
5	France	0.05	0.95
6	Germany	0.02	0.98
7	Greece	0.2	0.8
8	Hungary	0.18	0.82
9	Italy	0.03	0.97
10	Netherlands	0.10	0.90
11	Norway	1	0
12	Poland	0.07	0.93
13	Portugal	0.20	0.80
14	Romania	0.10	0.90
15	Spain	0.04	0.96
16	Sweden	0.06	0.94
17	Switzerland	0.6	0.4
18	Turkey	0.03	0.97
19	Ukraine	0.04	0.96
20	United Kingdom	0.03	0.97
21	Other European countries	2	X
Total		2.57	X

Source: calculated based on the data presented in Figure 7.

Conclusions

The conducted study on the consumption of primary energy by fuel types (oil, natural gas, coal, nuclear fuel, hydropower, and renewable energy) in European countries throughout 2023 utilized a correlation-regression approach to identify strong correlations between oil consumption and natural gas consumption (R^2 = 0.94), oil consumption and renewable

energy consumption (R^2 = 0.88), as well as natural gas consumption and renewable energy consumption (R^2 = 0.91). These high correlation values demonstrate the interdependence of the energy sources in European nations. The necessity of applying an environmental analysis method to assess the efficiency of primary energy consumption was substantiated using efficiency (inefficiency) coefficients and leveraging the advantages of the marginal nonparametric method and the coefficients method.

It is proposed that the consumption of primary energy per capita be used as the key performance indicator, as it allows for assessing the energy needs of the populations in each European country. For example, Finland, Sweden, and Norway, with per capita energy consumption of 85.5, 78.2, and 82.6 GJ, respectively, lead the efficiency line. All three operating environments were analyzed based on the results of the correlation-regression analysis, leading to the construction of an efficiency line, in which two out of three variants included positions for Finland, Sweden, and Norway. Only one variant showed two positions on the efficiency line: Finland and Norway.

Furthermore, inefficiencies were identified in the positions of the most developed European countries, such as Germany, the United Kingdom, France, Italy, Spain, and Turkey.

Future research should focus on calculating optimization indicators for primary energy consumption. Using the environmental analysis method, it is possible to determine the necessary increases in per capita energy consumption for the main highly developed European countries, alongside a reduction in the consumption of oil, gas, and renewable energy. Additionally, similar calculations to determine consumption efficiency can be conducted for other types of primary energy, such as coal, nuclear fuel, and hydropower, providing a comprehensive and objective picture of the adequacy of energy resources for European consumers.

The Authors have no conflicts of interest to declare.

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Ocena efektywności zużycia energii pierwotnej w gospodarkach europejskich: podejście oparte na korelacji i regresji

Streszczenie

Znaczenie energii pierwotnej w kontekście gospodarek europejskich jest powszechnie uznane, co podkreśla kluczową potrzebę rozwoju sektora energetycznego w celu wspierania rozwoju gospodarczego w badanych krajach. Zidentyfikowano główne wyzwania związane ze zużyciem energii, w tym nierównomierny rozkład zasobów energetycznych, specyficzne ograniczenia infrastruktury logistycznej oraz różnice w wykorzystaniu zasobów między poszczególnymi krajami. Podkreślono konieczność oceny efektywności zużycia energii pierwotnej w krajach europejskich, skupiając się nie tylko na efektywności poszczególnych państw, lecz także na szerszym kontekście środowiskowym, w którym funkcjonują państwa europejskie.

W celu zbadania wzajemnych powiązań między różnymi rodzajami zużycia paliw (ropa naftowa, gaz ziemny, węgiel, paliwo jądrowe, energia wodna i energia odnawialna) zastosowano analizę korelacji i regresji, co ułatwiło określenie gęstości powiązań oraz opracowanie modeli liniowych. Stwierdzono silną korelację między trzema głównymi rodzajami paliw: ropą naftową, gazem ziemnym i energią odnawialną. Analiza wykazuje wpływ zużycia ropy naftowej zarówno na zużycie gazu ziemnego, jak i energii odnawialnej, a także wzajemny wpływ zużycia gazu ziemnego na wykorzystanie energii odnawialnej.

W celu oceny efektywności zużycia energii pierwotnej przeprowadzono analizę z wykorzystaniem metody środowiska funkcjonowania, przyjmując zużycie energii pierwotnej na mieszkańca jako główny

wskaźnik wynikowy. Z analizy wynika, że zużycie energii pierwotnej na mieszkańca jest najważniejszym czynnikiem wpływającym na efektywność zużycia energii, co potwierdzają dane empiryczne z Finlandii, Norwegii i Szwecji.

Słowa kluczowe: energia pierwotna, efektywność zużycia energii, rodzaje paliw, metoda korelacji i regresji, analiza środowiska funkcjonowania