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Assessing the energy security of European countries in the resource and economic context

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Abstract

Research background: In recent years, much attention in the literature has been paid to the economic and environmental conditions of energy development as a key sector for the development of national economies. The issue of availability of individual energy resources and related energy security is receding into the background, most often due to the strong globalization of economies and the associated assumption of free international flow of goods and services, and thus practically unlimited possibilities of buying on the international commodity markets and energy exchanges. Nevertheless, the importance of energy security increases significantly in crisis situations.
Purpose of the article: Bearing in mind the circumstances indicated above, the main objective of this article is to assess the energy security of European countries carried out in the context of resource and economic conditions.
Methods: The article proposes its own methodological approach to the assessment of energy security based on the analysis of the energy mixes of 32 European countries and the availability of their own internal energy sources. In the process of classifying the studied economies into homogeneous groups in terms of resource and economic determinants (GDP per capita), principal component analysis was used.

Findings & value added: The theoretical and methodological added value of the article results from the development of the author's approach to the assessment of energy security using individual and aggregated energy sufficiency index. Empirical added value is related to the results of energy security assessment in European countries, which can be used in shaping energy policies. Therefore, most of the 32 European countries assessed have a low level of energy security, which is due to the dominant use of non-renewable energy resources in their energy mixes. Countries with a high level of energy security have their own non-renewable resources or use alternative energy carriers in the form of renewable sources, hydropower or nuclear energy.

Introduction

Energy is an industry of strategic economic importance in every country because it enables businesses and households to function (Chitedze *et al.*, 2021, pp. 855–873; Raghutla & Chittedi, 2021, pp. 290–307; Loizou *et al.*, 2015, pp. 393–411). Access to energy and heat is also a determinant of the progress of civilization. For these reasons, effective and efficient formulation of long-term energy policy is one of the key economic priorities.

In the last twenty years, energy issues have been widely discussed in the literature and economic practice due to two key problems, which are: the depletion of non-renewable resources (Bhat *et al.*, 2022, pp. 756–755) and the need to reduce carbon dioxide emissions in connection with the climate crisis (Davidson *et al.*, 2021; Chovancová & Tej, 2020), with the latter being particularly prominent in Europe pushing hard for the elimination of non-renewable energy sources and a zero-carbon economy (Redek *et al.*, 2020, pp. 11–29; Karaduman & Gonel, 2016, pp. 224–233).

Energy security, which — from a theoretical point of view — should be treated on an equal footing with economic and environmental priorities of energy policymaking, is less often addressed in the main research threads (Elbassoussy, 2019, pp. 321–342; Escribano Francés, 2011, pp. 39–59). Meanwhile, the prominence of this issue increases significantly in crisis situations that economies around the world have been forced to deal with in recent years. Undoubtedly, these include the pandemic caused by Covid-19 and the war in Ukraine (Qureshia *et al.*, 2022). In such situations, due to the intensification of threats, the need for security becomes more palpable and acute, as emphasized by the doctrine of public finance in arguing for the necessity of state financing of public goods.

Bearing in mind the above circumstances, the main objective of this article is to assess the energy security of European countries in the context of resource and economic conditions. To achieve such a goal, the analysis was carried out on the energy mixes and possibilities of energy production on their own of 32 European countries from 2016–2020. Moreover — in addition to resource determinants — in the course of research, economic determinants in the form of GDP per capita were taken into account due to its documented importance in shaping energy policy (Liu, 2021, pp. 588–607; Emirmahmutoglu *et al.*, 2021, pp. 2230–2241; Moshiri & Daneshmand, 2020, pp. 789–803; Sunny, 2017, pp. 1527–1541).

As part of the research methodology, a proprietary approach to assessing energy sufficiency was proposed, allowing the use of an available standardized database (*BP Statistical Energy Review*) and enabling comparative analysis of the results obtained. In the process of classification of the studied countries the principal component analysis was used.

In the next part of the article, literature studies on the economic and non-economic determinants of energy policy are presented. Next, the principles of research sample selection and the proposed methodological approach are presented. Finally, diagnostic conclusions and recommendations for shaping the energy policy in the current political and economic conditions were formulated.

Considerations and research presented in the article:

1. Expose the importance of security in energy policy, gaining particular significance in crisis situations;
2. Complement the previous research on the determinants of the national energy mix with a theme related to the adequacy of resources and energy security, which is much less frequently highlighted in the literature than environmental or economic issues;
3. Allow to verify previous conclusions on the effects of the choice of specific energy policy priorities on the level of energy security;
4. Provide information on the current resource adequacy of the analyzed European countries and the directions allowing for its effective increase, which, in the current geopolitical conditions, is of particular economic importance;
5. Present a universal and transparent methodological approach to the assessment of energy sufficiency that can be easily replicated and used in the course of similar studies;
6. Allow combining scientific and practical threads, which, in the case of issues related to energy strategies, strengthens the application value of research by providing decision makers with conclusions setting the directions of energy development.

The above elements constitute an original contribution of the article to the consideration of the functioning of the energy sector in national economies and the formation of effective and efficient energy policy.

Literature review

Energy policy determinants

The determinants of the energy policy are very diverse, nevertheless they can be divided into three main groups defining the triad of choices of energy development directions: economy + environment + security. In practice, this means access to our own cheap and environmentally-friendly energy sources. Simultaneous and sustainable fulfilment of the indicated expectations in practice is extremely difficult, which is due to several circumstances.

Firstly, the development of green energy sources requires extensive changes not only at the level of national energy policies, but most importantly at the level of energy infrastructure (Best, 2017, pp. 77–83). This includes the use of renewable energy sources, as well as hydropower or nuclear energy in place of the non-renewable resources used most often so far in most of the world's economies (Ma *et al.*, 2022, pp. 217–229).

Such changes mean the necessity to create a production and transmission base practically from scratch, which in turn is associated with significant capital expenditure and a long investment perspective. The above circumstances are not conducive to developing and underdeveloped economies, which lack sufficient resources — and often technologies and organizational agility — to carry out an effective and radical energy transition (Bashir *et al.*, 2021, pp. 570–587; Bamati & Raoofi, 2020, pp. 946–955; Li *et al.*, 2016b). For these reasons, research shows that green energy transition is the fastest and most effective in developed and highly developed countries with above-average per capita national income levels (Lee *et al.*, 2022; Merk *et al.*, 2019; Destek & Aslan, 2017, pp. 757–763).

The importance of economic considerations in national energy policy making is also emphasized by the need to fund and subsidize renewable energy sources (Adams & Apio, 2018, pp. 755–767; Gebhardt, 2009, pp. 71–90). It represents an additional burden on state budgets, which can be afforded mainly by the wealthiest economies which have the resources to subsidize energy production, and/or whose residents are able to accept and bear the costs of the energy transition.

Secondly, the ability to use indigenous energy resources — both non-renewable and renewable — is dependent on geological, geographic, or climatic conditions that are beyond government control. Non-renewable natural resources have predetermined characteristics, such as distribution, quality, or sufficiency. Renewable energy, on the other hand, depends on convenient weather conditions that change over time and space (Tröndle *et al.*, 2020, pp. 1929–1948; Fadly & Fontes, 2019, pp. 422–435).

Third, consideration of environmental determinants of energy development is not seen as a priority everywhere. The greatest importance to this group of determinants of energy policy is currently attached by the European Union, where legal and financial restrictions are in place to effectively reduce carbon dioxide emissions and limit the use of non-renewable resources in energy (von Lucke, 2021; Hainsch *et al.*, 2022; Balcerzak & Pietrzak, 2016, pp. 66–81). In other regions of the world, including in particular Asian countries, environmental goals are recognized, but not placed before economic, financial or independence goals (Bor & Zhang, 2010, pp. S1–S2).

However, it is worth mentioning that the results of previous studies on the relationship between energy security and environmental policies are inconclusive (Johansson, 2013, pp. 598–605; Francés *et al.*, 2013, pp. 549–559). Guivarch *et al.* (2015) and Guivarch and Monjon (2017) argue that an excessive focus on environmental goals can result in reduced energy security, especially in the long term where permanent and difficult to reverse changes occur (Guivarch *et al.*, 2015; Guivarch & Monjon, 2017, pp. 530–541). In turn, the results of studies by Cergibozan (2022) conducted in OECD countries indicate a positive impact of renewable energy sources on the level of energy security, including in particular hydropower and wind energy.

With the development of renewable energy, the literature also pays attention to the technological aspects of competitiveness of the domestic energy industry, treating them as one of the main determinants of energy policy. According to Schmidt *et al.* (2019), the technology of renewable energy generation is of particular importance in this regard. The authors also point out that much of the determinants of these technologies are political in nature, as politicians determine which RES carriers are priorities for national energy development.

Sevim (2016) and Anderson (2015) indicate that contemporary energy trends will be determined by several key circumstances. Among the most important trends, they point out attitudes toward nuclear power after the Fukushima disaster, climate policy, as well as the international energy market situation. The clash between economic priorities related to the demand for and prices of raw materials, the use of nuclear power plants in strengthening energy security, as well as the scope and possibilities of obtaining energy from renewable sources is clearly visible in this comparison. The current raw materials situation in Europe clearly indicates a change in the strength of influence of individual goals on energy policy making. In the wake of the war in Ukraine, issues related to maintaining energy security have become key, pushing environmental protection issues into the background. The current crisis has also significantly affected the prices of energy resources, exposing the role of economic conditions in the process of creating and implementing energy strategies (Ruiz & Koutronas, 2022).

Energy policy determinants and energy security

Focusing on the issues of energy security, it is also important to highlight its existing understanding (Cohen *et al.*, 2011, pp. 4860–4869; Winzer, 2012, pp. 36–48). Thus, according to the literature on energy security, it usually means the ability to meet a country's energy needs on its own, i.e., from energy sources owned and controlled by the country. Such a definition focuses on the supply side. However, Blum and Legey (2012, pp. 1982–1989) also draw attention to the demand side of this security related to the rational, reasonably stable and sustainable choices of energy consumers (Simanaviciene *et al.*, 147–157).

Maintaining energy security originally assumed the use of two strategies: restrictive or liberal (Constantin, 2005). The restrictive strategy advocates resource self-sufficiency or diversification of the energy mix to distribute risk. The liberal one advocates free shaping of the mix assuming freer and greater ability to use imports of non-renewable resources from different regions where they are available. In current practice, this usually means paying less attention to the priority of energy security.

In the current economic climate, the above list of strategies should be complemented by a strategy of sustainable energy policymaking, in which, in addition to the availability of energy resources, the environmental impact of their use is considered and taken into account (Blum & Legey, 2012, pp. 1982–1989).

Research results by Lange *et al.* (2019) show that such an energy strategy is fostered by the hierarchical mode of state management, in which the directions of energy development are determined at the central level, while operational activities for its implementation are carried out at regional and local levels.

In the literature, energy security issues are mostly described in the context of other energy policy-making priorities, including primarily environmental ones. The assessment of energy security itself is given less attention, which is indicative of a liberalized approach to energy independence, especially in Europe. The reason for this may be that the prioritization of energy security often takes place at the expense of giving up environmental goals, which is not a popular approach. This is also pointed out by Novikau

(2021), who, analyzing the Russian energy strategy, concludes that the low-carbon energy transition may pose a serious threat to energy security. Therefore, in the process of choosing energy carriers, Russia focuses on minimizing the risk of losing energy security by choosing those energy sources that it has control over, consciously giving up on maximizing environmental goals.

The issue of energy security being offset by environmental and economic priorities is also highlighted by Proedrou (2022) in his analysis of Greek energy policy. His research and insights provide a form of warning against the government's excessive focus on a low-carbon energy transition that could lead to a loss of national energy independence.

The above findings are not always confirmed by other researchers. Hassan *et al*. (2021) conclude that a low-carbon energy transition can be conducive to maintaining or improving energy security, provided that it is accompanied by energy efficiency enhancements associated with the use of modern RES technologies already mentioned.

Similar conclusions are reached by Trifonov *et al*. (2021) in their study of six countries in Eastern Europe, the Caucasus and Central Asia on the impact of renewable energy sources on energy security. They conclude that RES can contribute to energy security if accompanied by diversification of energy sources in energy mixes, including the use of different RES.

Linas *et al.* (2022) try to approach the determinants affecting security in a holistic way. Their research in the Lithuanian economy shows that the level of energy security is positively influenced by a significant diversity of energy sources, including both their supply and production. This approach increases the resilience of the energy system to demand and supply energy shocks.

It is also worth mentioning that the question of perception and, consequently, the choice of energy policy priorities by European societies depends on their history of experience, level of prosperity and represented political option. Indeed, Tosun and Mišić's (2020) research shows that for Western European citizens with left-wing political views, the key goal in energy policymaking is to reduce greenhouse gas emissions and avert climate catastrophe. Meanwhile, Central and Eastern European citizens with a right-wing worldview are strongly in favor of increasing the level of energy security, even at the cost of giving up environmental goals.

It follows from the above considerations that the choice of directions of energy policy making in the context of the above-mentioned triad: economy + environment + security depends on the individual goals of a given economy, the level of its economic and civilizational development, as well as legal and environmental conditions, and certainly in practice it is not sustainable (von Hippel *et al.*, 2011, pp. 6719–6730).

Energy policy in European countries

This paper focuses on European countries where environmental objectives are prioritized in energy policies, therefore further literature review refers to countries located in this region. It is noteworthy here that the pro-environmental policy of the European Union has taken a rather radical form in recent years, which is limited not only to the formulation of guidelines on the directions of energy development (Hofmann & Staeger, 2019), but also includes a number of mandatory procedural provisions, often resulting in interference in the formation of the terms of international agreements between EU countries and external contractors. Thaler and Pakalkaite (2021) describe this "real-time compliance" phenomenon in more detail and point to its implications for both energy security and attitudes towards European integration. Similar conclusions are reached by Solorio and Jörgens (2020), who — on the basis of an analysis of the impact of EU regulations on the energy decisions of 10 European countries — conclude that the commonality of energy policies may result in de-europeization and weakening in the EU. According to Keypour and Ahmadzada (2022), the securitization of energy in the EU is also not conducive to inducing countries outside the community to join in achieving EU environmental goals.

Due to the prioritization of environmental objectives in Europe, the transformation of energy mixes focuses on maximizing the use of renewable energy sources. The best results in this area are achieved by highly developed Scandinavian countries. One of the undisputed leaders in terms of the desired pro-environmental changes in the energy mix in Europe is Finland, which has been effectively reducing carbon dioxide emissions for many years, while increasing its energy independence (Trotta, 2020). Economies successfully reducing carbon emissions include Sweden, Germany, Belgium, the UK, the Netherlands, and France (Goh & Ang, 2018; Saidi & Omri, 2020; Li *et al.*, 2016a).

The above results clearly indicate that highly developed economies are better at achieving environmental goals, while the process of low-carbon energy transition is slower and more problematic in countries struggling with economic difficulties. Proedrou (2019) also points this out when characterizing Greece's energy policy. Less developed countries are also more likely to consider the choice of nuclear energy as part of the diversification of energy sources, as indicated by the examples of the Czech Republic or Turkey, among others (Sever, 2019). It is a source that promotes energy security and reduces greenhouse gas emissions. However, its use was negatively affected by the Fukushima power plant accident mentioned in the framework of contemporary determinants of energy policy.

Nevertheless, despite the exposure of environmental objectives in some European countries as a result of the economic crisis associated with the Covid-19 pandemic, a departure from pro-environmental energy policy is observed. This phenomenon is described by Prontera (2021) on the example of Italy. Her research shows that politicians currently shaping the structure of the energy mix place economic goals above environmental ones, very often nullifying the achievements of the energy transition to date. This is quite a dangerous phenomenon, not only because of the destruction of the effects of change, but also because of the lengthiness of all the processes involved in transforming the energy structure. It is worth mentioning that similar observations are also described by Bürgin and Oppermann (2019), using the example of the Turkish economy. In this context, Bocquillon and Maltby (2020) draw attention to a certain sluggishness of European countries in the process of introducing a common energy policy, which manifests itself in formal acceptance and support for EU guidelines, while slowing down changes and prioritization of economic objectives in national energy policies.

As shown by Morales-Lage *et al.* (2019), CEE countries cope significantly worse with the implementation of EU climate policy, confirming an earlier observation relating to the problems of implementing low-carbon energy mixes in developing countries. Nevertheless, also in this region there are countries effectively limiting carbon dioxide emissions, which include Slovenia, Slovakia and the Czech Republic (Ptak, 2009, pp. 99–107).

It is worth adding, however, that despite the successes in the implementation of the EU climate policy, the above-mentioned countries are still separated by a considerable distance from the countries of Western Europe, as pointed out by Taušová *et al.* (2022) in comparative analyses conducted for the Visegrad Group countries and the EU on the effectiveness of implementation of environmental policy and sustainable development principles.

The problems of Central and Eastern European countries with the introduction and use of renewable energy sources are also emphasized by Chomać-Pierzecka *et al.* (2022), investigating the possibilities of using RES in Poland and the Baltic countries (Latvia, Estonia and Lithuania).

Previous research also suggests that one of the countries that has fared less well in the energy transition is Poland, where developing fixed, consistently implemented energy goals has been and remains very difficult.

This is pointed out by Ostrowski (2021), among others, who raises the issue of strong politicization of Polish energy policy and its corruption. The latter factor also hinders effective energy transition in other developing or emerging countries, as indicated also by Fahad *et al.* (2022) in research conducted in the Pakistani economy.

The variation in the level and pace of the transformation of the European energy sector has been the subject of much criticism. Restrictive energy policies are accused, among other things, of favoring developed countries with good initial conditions for energy transition and geographically privileged in their ability to use renewable energy sources (Rečka & Ščasnýac, 2018).

The European energy transition has also been criticized for its regular dependence on the supply of energy resources from Russia. As Ostrowski (2020) points out, over the past two decades, the European debate on energy security has focused primarily on the countries of Central and Eastern Europe and their dependence on non-renewable raw material supplies from Russia. At the same time, however, Western countries have been developing energy infrastructure connecting Europe to Russia, despite objections and warnings from the United States and NATO. This led to serious turbulence in the European and global markets for energy resources after the outbreak of war in Ukraine (Adekoya *et al.*, 2022).

The aforementioned conclusions do not allow for an unambiguous assessment of the level of energy security and its determinants. In most of the analyzed studies, considerations are carried out on the basis of case studies and diverse research methodology. This makes it impossible to make universal comparisons on an international scale and constitutes a research gap that needs to be filled. This gap became the main rationale for undertaking the topic of energy security assessment in European countries.

Additional circumstances justifying the undertaking of this research include:

1. The focus of European countries practically exclusively on one element of the triad shaping energy policy, which is the environment;
2. The small number of studies on energy security compared to publications describing environmental issues, including primarily the issue of the use of renewable sources undertaken in the last decade;
3. The growing threat to continuity and sufficiency of supply of non-renewable natural resources in connection with the war in Ukraine and Covid-19 pandemic.

This article attempts to assess energy security, which is gaining renewed importance in the current political and economic environment.

Research method

The research process used data on energy consumption and production in the studied countries, annually published in the BP Statistical Review of World Energy and Eurostat data on Gross Domestic Product per capita. The period of analysis covered 2015–2020, which, on the one hand, made it possible to take into account the most recent state of the energy mixes of the studied countries, and on the other hand, made it possible to average short-term proportions of energy consumption for comparison and classification purposes. The data for 2021 were not included in the analyses due to the fact that they were not yet available at the time the article was prepared. Attempts were made to compensate for this lack with references to the situation on the energy market after the Covid-19 pandemic and during the war in Ukraine.

The availability of continuous and complete time series data describing the above-mentioned variables for European countries made it possible to include 32 countries in the research sample.

The main objective of the research is to assess the energy security of European countries in the context of resource conditions (the structure of the energy mix and ownership of own non-renewable resources) and economic conditions (GDP per capita). Furthermore, the author of the article seeks answers to the following research questions:

RQ1: *To what extent do the European countries surveyed use renewable and non-renewable energy sources?*

RQ2: *What proportion of non-renewable resources can the surveyed countries obtain on their own and how does this affect their energy sufficiency?*

RQ3: *What energy mix structure is conducive to a high level of energy security?*

To achieve the main objective and answer the above questions, the author's research approach was applied including the stages and methods synthetically presented in Table 1.

At the first stage of the study, the structure of the energy mixes of the studied countries in 2015–2020 was determined, which allowed to ascertain the scale of use of individual energy sources and provided an introduction to further analysis allowing to assess the extent of dependence of the studied countries on non-renewable energy carriers.

Next, an answer was sought to the question of the possibility of satisfying the energy needs identified at the first stage from own energy resources. For this purpose, at the second stage of research, the production of given non-renewable resources (oil, gas, coal) was compared with the consumption of these resources. In this way, an absolute indicator of the sufficiency of non-renewable resources was obtained, calculated as follows:

$$u_i = \frac{P_i}{C_i} \tag{1}$$

where:
P_i own energy production from the i-th source;
C_i energy consumption from the i-th source.

In the case of renewable sources and nuclear energy, the value of the above indicator was assumed to be 1 (100%), since these sources are located within the country and the energy obtained from their use can be transmitted directly to the national energy networks. Thus, these are sources that naturally promote energy independence.

In the third stage of the study, the relative energy sufficiency indexes were aggregated into a summary sufficiency index, the value of which allows assessing the extent, to which it is possible to meet the demand for electricity on one's own, that is, using one's own energy carriers.

$$I_s = \sum_{i=1}^{n} u_i \times C_i \tag{2}$$

where:

$$u_i = \frac{P_i}{C_i} \tag{3}$$

P_i own energy production from the i-th source;
C_i energy consumption from the i-th source.

In the final, fourth, stage of research, selected countries were classified taking into account three key criteria for energy security: the structure of the energy balance, resource adequacy as a resource factor and the amount of GDP per capita as an economic factor. In the classification process, the principal component analysis was used, which allows to minimize the number of examined factors and limit them to those that most strongly affect the phenomenon under study (Jolliffe, 2002; Hotelling, 1933, pp. 498–520; Hotelling, 1936, pp. 321–377). In this way a relatively homogeneous set of countries with a similar level of energy security determined by the above-mentioned factors was obtained.

Before conducting the principal components analysis, the validity of its use is assessed by:

- Bartlette's test verifying the hypothesis that the correlation coefficients between the studied variables are zero (the correlation matrix is an identity matrix);
- Kaiser-Mayer-Olkin (KMO) coefficient checking the degree of correlation of primary variables. The value of KMO coefficient belongs to the range <0, 1> (values below 0.6 indicate that there is no basis for conducting principal components analysis).

Additionally, in the process of selecting the number of main components, the following are used:

- scree chart showing the rate of the eigenvalue contribution (flattening moment of the above-mentioned chart);
- Kaiser criterion stating that the eigenvalue of the principal components should be greater than 1.0 or very close to 1.0.

In the course of conducted considerations, the data in stages 1 and 2 were averaged for the years 2015–2020. It should be emphasized, however, that the proposed universal research approach makes it possible to perform the procedure for a selected period. The purpose of averaging carried out in this article was to cover the analysis of the medium-term period of energy policy implementation. Focusing on a single period could distort the results of the analysis in the case of incidental deviations from the adopted directions of meeting energy needs.

The methodology described above in the section on aggregate and individual indicators of energy resource adequacy is the author's own proposal, which allows for efficient assessment of the level of energy security of a given country using one-dimensional publicly available data on electricity consumption and production. This provides a basis for international comparisons on a broad and homogeneous scale and is the author's methodical contribution to research on the formation of energy balances.

In the further part of the article, the proposed research approach is used to assess the security level of 32 European countries. Such a comparative analysis has not been conducted before. Its main advantage is the inclusion of a large number of countries and the assessment using uniform methodological criteria. The compared countries are, of course, characterized by a different set of resource determinants, also depending on geographical location, but the author treats them as input variables and existing determinants of energy policy (difficult or sometimes impossible to change), and the main purpose of the study is to assess the level of energy security, regardless of what determinants are associated with it. It should be emphasized, however, that the obtained classification of countries allows to select those units that are the most effective, and this, in turn, provides a basis for indicating the energy policy determinants characteristic of them and formulating recommendations to less effective economies.

Results

In the first stage of the research, the structure of energy mixes of the studied countries was determined on the basis of the arithmetic average of shares of individual energy sources in total energy consumption in 2015-2020. The results are presented in Table 2.

The following conclusions can be drawn from Table 2 data:

1. The energy mixes of almost all the European countries studied were dominated by non-renewable energy sources. The share of non-renewable sources in energy consumption was clearly dominant, exceeding 50%. The exceptions in this respect were only 4 out of 32 countries, i.e., Norway, Sweden, Iceland and Switzerland (share of non-renewable sources less than 50%).
2. 12 out of 32 countries used nuclear energy in their energy mixes, the share of which ranged as follows: 7.41% to 37.45%.
3. Hydropower was used extensively in: Austria, Iceland, Norway, Sweden and Switzerland.
4. Renewable energy sources in most of the countries were only a supplement to the energy mix. Their share in meeting the energy needs was the highest in Denmark and Iceland.

In view of such a high share of non-renewable energy sources in the energy mixes of European countries, the next stage sought to answer the question about the possibility of satisfying consumer needs through their own production of petroleum, gas or coal. These potentials averaged over the study period are presented in Table 3.

The data in Table 3 shows that petroleum as an energy resource was produced in only 5 of the 32 countries surveyed (Denmark, Italy, Norway, Romania and the United Kingdom). A few more, i.e., 8 countries were able to at least partially cover their own needs for gas use in power generation, but full coverage was only possible in 4 countries (Denmark, Netherlands, Norway and UK). Ten countries produced hard coal, which could fully cover the needs of the power sector in only 3 of them (Austria, the Czech Republic and Poland).

The above conclusions indicate high dependence of the studied countries on external supplies of non-renewable energy sources and low energy security. It results from the high share of these raw materials in the energy mix and very low possibilities of satisfying them on their own.

In order to determine the scale of sufficiency of own energy resources, the energy sufficiency index described in the methodological part was calculated. Assuming that:

1. The satisfaction of the needs for the use of non-renewable sources occurs at the level specified in Table 2 (whereby if the values in Table 2 exceeded 100%, their value was assumed to be 100%, which corresponds to the assumption that a country is able to satisfy a given energy need in full, with any surplus being a source of potential export); no substitution between energy sources was assumed;
2. Nuclear energy, hydropower and renewable resources are fully utilized for own needs (production-to-consumption ratio = 1 (100%)).

The results of energy sufficiency calculated in this way are shown in Figure 1.

According to the results, a high sufficiency of over 80% characterized countries such as: Denmark, Norway, the United Kingdom, Romania and Finland. In contrast, the lowest values (below 15%) were achieved by: Cyprus, Estonia, Lithuania and Luxembourg. The countries with the highest energy independence therefore include countries that use non-renewable resources to a large extent and have a high capacity to obtain them from their own sources, or countries with low use of non-renewable resources and high use of hydropower, nuclear energy or/and renewable sources.

In the analysis, apart from the resource determinants, the level of GDP per capita was also taken into account as an important economic factor influencing the structure of the energy mix. Its average values for the research period of the factor are presented in Figure 2.

The data presented in Figure 2 reflect the very large income disparity between the studied countries, which is best illustrated by the difference in GDP per capita for Luxembourg and North Macedonia of almost 89 thousand EUR. The group of countries with the highest income (over 40,000 EUR) includes: Switzerland, Sweden, Norway, the Netherlands, Luxembourg, Ireland and Denmark. The earlier analysis shows that most of them are also countries that have successfully moved away from non-renewable energy sources (Switzerland, Sweden, Norway and Denmark).

The countries with the lowest GDP per capita (below 15,000 EUR) included: Turkey, Romania, Poland, Northern Macedonia, Lithuania, Latvia, Hungary, Estonia, Croatia and Bulgaria. This confirms the results of previous studies, which show that a low level of GDP per capita is associated with the use of traditional energy sources and a low level of progress in energy transition aimed at reducing greenhouse gas emissions.

In further analysis, the resource and economic determinants described above were combined and an attempt was made to systematize the studied countries while taking into account the following variables:

1. Structure of the energy mix divided into renewable and non-renewable;
2. Energy sufficiency;
3. GDP per capita as an economic determinant affecting the structure of the energy mix.

This task was performed using principal components analysis and the results are presented in Figure 3.

Before performing the principal components analysis, the validity of its use was assessed by means of:

1. Bartlett's test,
2. Kaiser-Mayer-Olkin coefficient.

The p-value of Bartell's statistics, p = 0.000014 and the KMO coefficient = 0.7063, indicates the validity of the principal component analysis. Additionally, the acquired eigenvalues indicate that the two main components will allow for a good limitation of dimensions. The eigenvalue for the first component is 2.3218 and the percentage of the variance it explains is 58.06. The second component explains less variance, because it is 20.60%, and its eigenvalue is 0.8241. Moreover, when analysing the scree plot, it can be concluded that the declining line does not change into a horizontal one until the 3rd main component.

According to the results presented in Figure 3, most of the countries studied are distributed in the 2nd and 3rd quadrant of the coordinate system. Basically, these are countries with low or average energy sufficiency with a high share of non-renewable sources in energy production. Such a distribution of most of the surveyed European countries points to major problems for European economies in maintaining energy independence. The current geopolitical situation and the associated difficulties in moving away from the supply of non-renewable energy resources from Russia have revealed and highlighted these problems. In addition, it should be added that, in quadrant II, there are countries with a higher level of GDP per capita than those located in quadrant III. These are, therefore, countries that are more predisposed to the implementation and use of renewable energy sources, which is reflected in the graph by their proximity to quadrants I and IV.

In quadrants I and IV there are countries with higher energy sufficiency and a higher share of renewable sources, hydropower or nuclear energy in the energy mix. However, quadrant I is represented by countries with a higher level of GDP per capita. In quadrant IV there are less developed countries with quite diverse energy mixes. It is worth noting here that the percentage distribution of the analyzed factors indicates that the largest contribution to the assessment of the level of energy security is the composition of the energy mix. The economic factor in the form of GDP per capita does not play such a significant role in the classification.

It should also be noted that there are 3 countries that clearly stand out from the rest of the studied group, namely, Finland, Iceland and Norway. These countries to a large extent use atypical energy mixes with a high share of nuclear and hydropower. They are also characterized by an above-average level of GDP per capita and very high energy sufficiency.

Accordingly, maintaining energy security is facilitated by the use of one's own energy sources, which is obvious, but in the case of the European countries studied, these sources can be practically only: renewable sources, hydropower or nuclear energy, since most of these countries do not have the possibility of obtaining non-renewable energy sources on their own. This situation is currently taking place, but will also continue in the future, which is justified by the information about proven reserves of non-renewable raw materials, which are located outside Europe.

Discussion

The obtained research results show that most of the studied European countries pursue a liberal energy security policy because, despite the lack of their own non-renewable energy resources, they assume the free possibility of external supply from international raw material markets (Blum & Legey 2012; Constantin, 2005). Such a policy, however, comes at the cost of deterioration or loss of energy security. This confirms the results of previous studies by Novikau (2021) and Proedrou (2022) on the Russian and Greek economies.

Nevertheless, in the studied group, the Scandinavian countries stand out, which effectively implement a strategy of sustainable, low-carbon energy and at the same time maintain a very high level of energy security. This is done mainly by using a mix of renewable resources, hydropower and nuclear energy. We should also add that these are also countries with above-average GDP per capita. The above observations support the conclusions of previous studies about the primacy of the Scandinavian countries in the energy transition (Trotta, 2020; Goh & Ang, 2018; Saidi & Omri, 2020; Li *et al*., 2016a) and about the more effective handling of this transition in highly developed countries (Lee *et al*., 2022; Merk *et al*., 2019; Destek & Aslan, 2017, pp. 757–763).

One could also agree in this context with Schmidt *et al.* (2019), who highlight the role of access to modern technologies in shaping energy security. In highly developed countries, such access is certainly easier, which favors both the low-carbon transition and the maintenance of energy independence. In addition, the obtained results indicate the effectiveness of those energy strategies, in which a large diversity of energy carriers is used, as exposed in their studies by Trifonov *et al.* (2021) and Linas *et al.* (2022).

As the examples analyzed in the article show, the use of nuclear energy allows both to increase energy security and achieve climate policy goals. Countries that have decided to use this source in their energy balances achieve very good positions in the ranking. In the current geopolitical conditions, the importance of nuclear energy in meeting European energy needs may increase, despite the negative perception of this source after the Fukushima disaster (Sevim, 2016; Anderson, 2015).

An assessment of energy security in CEE countries reinforces the above conclusions. These countries have a lower level of energy sufficiency and security, and a significantly lower GDP per capita than the aforementioned leaders. Against this background, the Czech Republic stands out, as it has an above-average level of energy security and is systematically moving away from non-renewable energy resources, replacing them with nuclear energy and, to a lesser extent, renewable resources and hydropower. This country is also highlighted in previous studies in the context of effective carbon dioxide reduction (Morales-Lage *et al*., 2019).

The Czech Republic, together with Slovakia, also stands out from the rest of the Visegrad Group countries in terms of relatively low use of non-renewable sources in the energy mix. Poland and Hungary are not successful in this regard (the share of non-renewable sources exceeds 94% in these countries). Nevertheless, Poland — thanks to the possibility to use its own hard coal — performs much better in the assessment of energy sufficiency than Hungary, which does not have reserves of its own non-renewable resources. However, it is worth noting the progressive dependence of Poland on Russian supplies of energy resources observed in recent years and described by Ostrowski (2021), which may negatively affect the energy security of this country. It is also noteworthy that all the countries forming the Visegrad Group use renewable sources to a small extent, which indicates the problems in this area described by Taušová *et al.* (2022).

In the ranking of energy security, the Baltic countries fare even worse than the Visegrad Group countries. i.e.: Lithuania, Latvia and Estonia. This means that the weakness of the energy policy of these countries in terms of low-carbon transition (Chomać-Pierzecka *et al.*, 2022) is further exacerbated by the low level of sufficiency of their own energy resources.

Summarizing the results obtained, it can be concluded that the use of non-renewable resources in European energy mixes is not able to ensure energy security because increasing their share is very slow, expensive and dependent on climatic and geographical conditions, which refers to the conclusions of Guivarch *et al*. (2015) and Guivarch and Monjon (2017). In meeting environmental and sufficiency criteria at the same time, the mixes in which nuclear and hydropower are used perform much better, as confirmed by the examples of Norway, Iceland and Finland.

At the same time, it is worth emphasizing that, in the long term, nuclear energy performs better due to the lack of harmful effects on the environment and independence from geographical conditions. The role of this source in the energy balance is also strengthened by the very slow development of renewable energy sources in most of the countries studied, which makes it impossible to treat RES as an efficient and fully substitutable source of energy and an alternative to non-renewable resources.

Given the above, recommendations aimed at increasing energy security of the examined European countries should be focused on:

1. Monitoring the level of security and adjusting energy policies also to this criterion;
2. Carrying out the energy transformation taking into account not only renewable resources, but also the opportunities offered by nuclear and hydropower;
3. Continuing to work towards sustainable energy development, taking into account the proposals presented by Lange *et al.* (2019) regarding the adoption of a hierarchical approach to the implementation of the energy strategy (development of guidelines at the central level and delegation of operational tasks to the regional and local levels).
4. Developing systems of early response to economic and political crises, ensuring continuity and sufficiency of supplies of non-renewable resources, which still dominate in the energy of many European countries.

In the context of the above recommendations, it is worth referring to the determinants of the development of contemporary energy policies identified and described by Sevim (2016) and Anderson (2015). They included, first of all, the attitude to nuclear energy, climate policy and the situation on the international market of energy resources. It seems that, in the current geopolitical situation, the above-mentioned factors will still remain relevant, but their internal hierarchy will change, which means that economic goals related to the price and availability of energy resources will most likely prevail, pushing climate goals to the background.

Nuclear energy may also gain in importance. This is confirmed by trends already observed in economies less able to cope with the energy transition, as also described by Proedrou (2019), Prontera (2021), Bürgin and Oppermann (2019) and Bocquillon & Maltby (2020).

In light of the research results received and to date, it can also be concluded that the current situation of the energy commodity market in Europe is not conducive to the tightening of EU climate policy. The EU's actions in this regard were criticized already before the outbreak of the war in Ukraine, as clearly indicated by the considerations conducted by Hofmann and Staeger (2019); Thaler and Pakalkaite (2021); Solorio and Jörgens (2020) and Keypour and Ahmadzada (2022).

The intensification of problems related to meeting energy needs brought about by this crisis will most likely contribute to a shift away from liberal energy policies and give arguments to opponents of restrictive climate policies. This phenomenon may intensify especially in Central and Eastern European countries, which, as shown in the research, are poor at low-carbon energy policies and maintaining energy security, and where, as Tosun and Mišić (2020) observe, societies are in favor of prioritizing energy security at the expense of abandoning environmental goals.

The observations described above may additionally contribute to weakening the cohesion of the European Union, which can already be observed in the case of Hungary, which denies the demand to resign from the supply of energy resources from Russia. This process has also already been noticed by Thaler and Pakalkaite (2021) and Keypour and Ahmadzada (2022).

Conclusions

The article develops the author's approach to energy security assessment, which allows to transparently and universally assess the degree of energy sufficiency of individual countries in any period and geographical location. The presented methodology can be used in international comparative analyses and in the process of monitoring and assessing the current state of raw material security. Additionally, thanks to the calculation of individual and aggregated resource adequacy index, it is possible to assess energy security for both individual energy sources and the entire energy mix. The presented evaluation approach is the main theoretical and methodological contribution of the article to the development of research on energy strategies.

Empirical added value of the article is related to the results of energy security assessment in European countries, which can be used in shaping energy policies. Therefore, the energy sufficiency of most of the European countries studied was low or very low during the period analyzed. Only 11 of the 32 countries could cover their electricity demand by more than 50%. The highest sufficiency (over 80%) was achieved by: Denmark, Norway, the United Kingdom, the Czech Republic, Romania and Finland. These countries should, therefore, be considered energetically secure. In contrast, the lowest values (below 15%) were achieved by: Cyprus, Hungary, Iceland, Lithuania and Luxembourg, which must be considered as strongly dependent on external suppliers of energy resources.

The low energy sufficiency and security of the studied countries is mainly due to the significant extent of the use of non-renewable raw materials in the energy mixes and the inability to obtain them independently. This indicates significant difficulties in moving away from non-sustainable energy sources and the slowness of the energy transition, which is not accelerated even by the restrictive environmental policy of the European Union.

The high level of energy security was fostered by two strategies:

1. Basing on own non-renewable energy sources with their high share in the energy mix;
2. Low-carbon transition of the energy sector with significant diversification of energy sources based on simultaneous use of various RES, hydropower and nuclear energy.

It is worth emphasizing that nuclear energy is currently underestimated and has great development potential, as it supports the implementation of environmental policy and is not dependent on climatic or geographical conditions as is the case with RES.

In the most difficult situation, in terms of energy security, are countries using mainly non-renewable sources without the possibility of obtaining any of them on their own, and therefore almost entirely dependent on external supplies. Among them, a significant part is located in Central and Eastern Europe.

In the current geopolitical situation, associated with the suspension of supplies of non-renewable energy resources from Russia, the low energy independence of the studied countries may cause disruptions in the coverage of energy needs. It may also contribute to the individualization of energy policies in individual countries and a shift from EU climate goals to those related to energy security. Consequently, it may also lead to a weakening of ties within the EU if no pre-emptive countermeasures, such as joint negotiations of energy supplies or loosening of climate restrictions for the duration of the crisis, are implemented.

The main limitation of the research presented in this paper is some simplifications in the assumptions of the use of individual energy sources associated with averaging the data for the entire research period. Nevertheless, they allow to unify the methodology and make identical comparisons on a large scale. It is also limited by the use of fairly simple methods of analysis, which — nevertheless — allows for the establishment of a universal, readable and easily applicable framework for assessing energy security in practice.

Further analysis and research should take into account the actual and potential economic effects of low energy sufficiency with particular emphasis on crisis situations. They should also be oriented towards identifying pathways and scenarios for increasing the resilience of the economy to energy impasses.

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Annex

Table 1. The stages and research methods used to assess the level of energy security and classify the economies under study

Research	Methods
(1) Determination of energy mix structure	Averaged (for 2015-2020) values of percentage shares of individual energy sources including: – petroleum – natural gas – coal – nuclear energy – hydropower – renewable energy. Calculations were performed for the consumption value of each of the above-mentioned carriers expressed in exa-joules.
(2) Identification of the possibility of covering the demand for individual non-renewable sources on their own	Analysis of the averaged (for 2015-2020) volume of production of: petroleum, natural gas, coal and nuclear energy for the studied countries and its comparison with the demand for a given energy carrier (volume of consumption).
(3) Calculation of the summary adequacy index for the identified energy mixes, taking into account the possibility of covering the demand for individual sources on their own (Authors' proposal)	The summary sufficiency indicator for the identified energy mixes was calculated as follows: $$I_s = \sum_{i=1}^{n} u_i \times C_i$$ where: $$u_i = \frac{P_i}{C_i}$$ Pi – own energy production from the i-th source; Ci – energy consumption from the i-th source. The value of the sufficiency factor in absolute terms informs how much energy could be consumed assuming that a given country uses only its own resource sources. The reference of this value to the value of the actual energy consumption (including imports) allows the evaluation of the sufficiency of own energy sources in relative terms - in percentage terms.
(4) Classification of the countries studied in terms of resource and economic conditions	The classification was carried out while taking into account the following criteria: (1) Structure of the energy mix divided into renewable, non-renewable and nuclear sources; (2) Energy sufficiency calculated as described above; (3) GDP per capita as an economic determinant affecting the structure of the energy mix. In the process of classification of the studied countries, we used principal component analysis (PCA), which is one of the forms of factor analysis and enables the classification of the studied entities by reducing the dimensions that describe them to the most relevant (Jolliffe, 2002; Hotelling, 1933, pp. 498–520; Hotelling, 1936, pp. 321–377).

Source: own work based on: BP Statistical Review of World Energy (2021).

Table 2. Energy mixes of the studied European countries (shares of individual sources were calculated as an average from 2015–2020)

Country	Energy sources							
	Petroleum	Gas	Coal	Total Non-renewables	Nuclear energy	Hydropower	Renewable	TOTAL
Austria	36.25%	21.58%	8.40%	66.24%	0.00%	24.49%	9.27%	100%
Belgium	50.88%	23.89%	5.15%	79.92%	13.05%	0.11%	6.91%	100%
Bulgaria	25.99%	14.38%	30.46%	70.82%	19.02%	4.66%	5.50%	100%
Croatia	42.49%	29.09%	5.81%	77.40%	0.00%	16.91%	5.69%	100%
Cyprus	95.40%	0.00%	0.32%	95.71%	0.00%	0.00%	4.29%	100%
Czechia	23.58%	17.57%	37.62%	78.77%	15.21%	1.03%	4.99%	100%
Denmark	45.74%	16.11%	8.92%	70.77%	0.00%	0.02%	29.21%	100%
Estonia	24.13%	6.88%	61.58%	92.59%	0.00%	0.10%	7.32%	100%
Finland	34.32%	6.46%	14.21%	54.99%	18.51%	11.71%	14.80%	100%
France	32.10%	16.04%	3.29%	51.43%	37.45%	5.36%	5.76%	100%
Germany	36.98%	24.45%	21.95%	83.38%	0.00%	1.39%	15.23%	100%
Greece	54.54%	14.91%	17.20%	86.65%	0.00%	3.90%	9.45%	100%
Hungary	40.71%	43.02%	10.81%	94.54%	0.00%	0.26%	5.19%	100%
Iceland	18.10%	0.00%	2.15%	20.25%	0.00%	56.49%	23.26%	100%
Ireland	47.07%	28.10%	10.04%	85.21%	0.00%	1.09%	13.70%	100%
Italy	39.14%	38.67%	5.84%	83.64%	0.00%	6.12%	10.24%	100%
Latvia	47.90%	29.08%	1.07%	78.04%	0.00%	15.31%	6.65%	100%
Lithuania	53.52%	33.49%	3.25%	90.26%	0.00%	1.55%	8.20%	100%
Luxembourg	73.44%	18.47%	1.21%	93.13%	0.00%	0.56%	6.31%	100%
Netherlands	46.73%	36.65%	9.84%	93.22%	0.98%	0.02%	5.78%	100%
North Macedonia	40.88%	8.20%	36.53%	85.61%	0.00%	12.87%	1.52%	100%
Norway	21.08%	8.54%	1.74%	31.36%	0.00%	65.51%	3.13%	100%
Poland	30.15%	16.80%	47.13%	94.08%	0.00%	0.45%	5.47%	100%
Portugal	45.87%	19.70%	9.32%	74.90%	0.00%	9.20%	15.90%	100%
Romania	30.58%	28.82%	15.54%	74.94%	7.50%	10.66%	6.90%	100%
Slovakia	25.05%	25.84%	18.86%	69.75%	20.55%	5.71%	3.99%	100%
Slovenia	37.23%	10.76%	16.29%	64.28%	19.04%	14.05%	2.64%	100%
Spain	46.26%	20.46%	6.81%	73.53%	9.34%	4.51%	12.62%	100%
Sweden	26.10%	1.64%	3.74%	31.48%	25.59%	27.59%	15.34%	100%
Switzerland	38.41%	10.76%	0.39%	49.56%	18.25%	28.74%	3.45%	100%
Turkey	31.53%	27.00%	26.46%	84.99%	0.00%	10.12%	4.88%	100%
United Kingdom	38.77%	35.58%	5.45%	79.81%	7.41%	0.68%	12.10%	100%

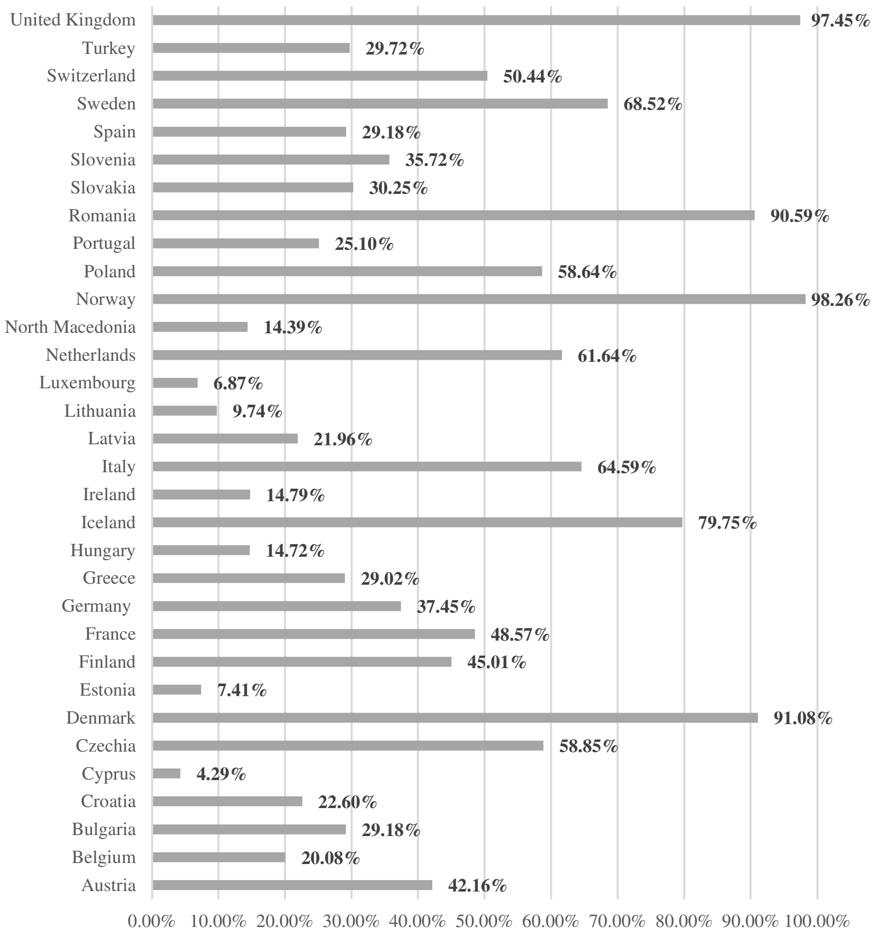
Source: own work based on: BP Statistical Review of World Energy (2021).

Table 3. Ratio of production of non-renewable sources to their consumption in the studied countries (ui)

Country	Energy sources		
	Petroleum	Gas	Coal
Austria	0.00%	0.00%	117.58%
Belgium	0.00%	0.00%	0.00%
Bulgaria	0.00%	0.00%	0.00%
Croatia	0.00%	0.00%	0.00%
Cyprus	0.00%	0.00%	0.00%
Czechia	0.00%	0.00%	118.08%
Denmark	4,021.10%	166.59%	0.00%
Estonia	0.00%	0.00%	0.00%
Finland	0.00%	0.00%	0.00%
France	0.00%	0.00%	0.00%
Germany	0.00%	21.30%	71.17%
Greece	0.00%	0.00%	91.11%
Hungary	0.00%	0.00%	85.71%
Iceland	0.00%	0.00%	0.00%
Ireland	0.00%	0.00%	0.00%
Italy	113.26%	23.51%	0.00%
Latvia	0.00%	0.00%	0.00%
Lithuania	0.00%	0.00%	0.00%
Luxembourg	0.00%	0.00%	0.00%
Netherlands	0.00%	149.69%	0.00%
North Macedonia	0.00%	0.00%	0.00%
Norway	41,821.94%	1,166.50%	0.00%
Poland	0.00%	33.27%	127.83%
Portugal	0.00%	0.00%	0.00%
Romania	1,498.81%	80.18%	76.19%
Slovakia	0.00%	0.00%	0.00%
Slovenia	0.00%	0.00%	0.00%
Spain	0.00%	0.00%	39.84%
Sweden	0.00%	0.00%	0.00%
Switzerland	0.00%	0.00%	0.00%
Turkey	0.00%	0.00%	55.60%
United Kingdom	3,672.93%	111.96%	53.23%

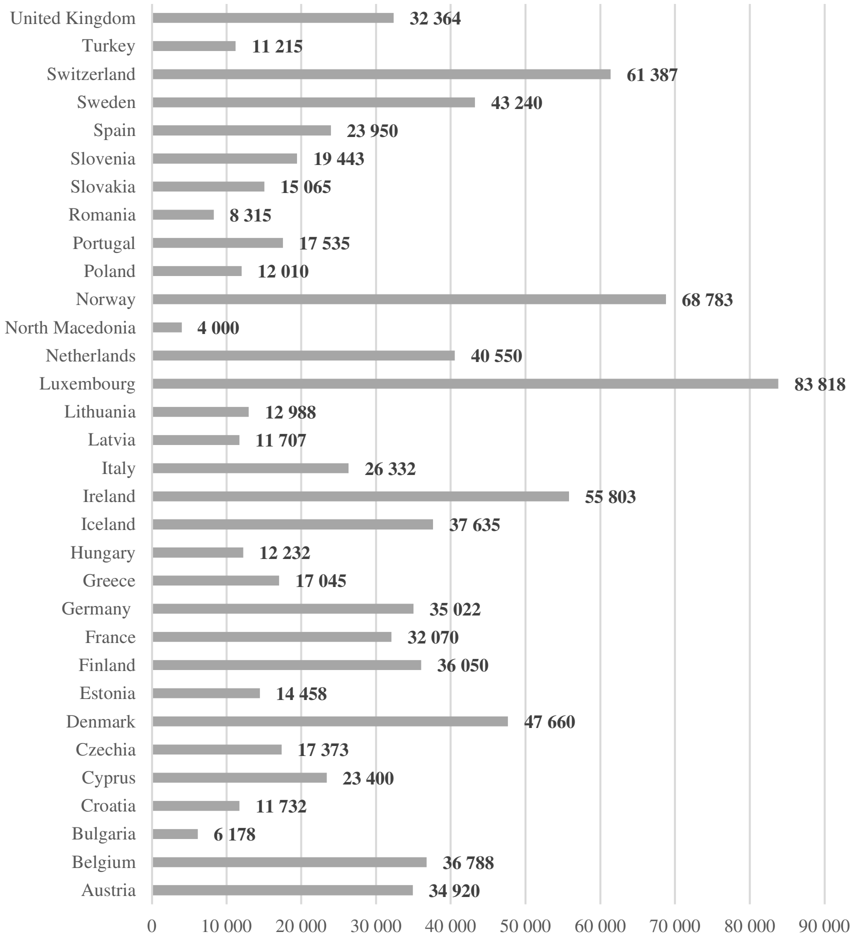
Source: own study based on: BP Statistical Review of World Energy 2021.

Figure 1. Energy sufficiency of surveyed European countries averaged over 2016–2020



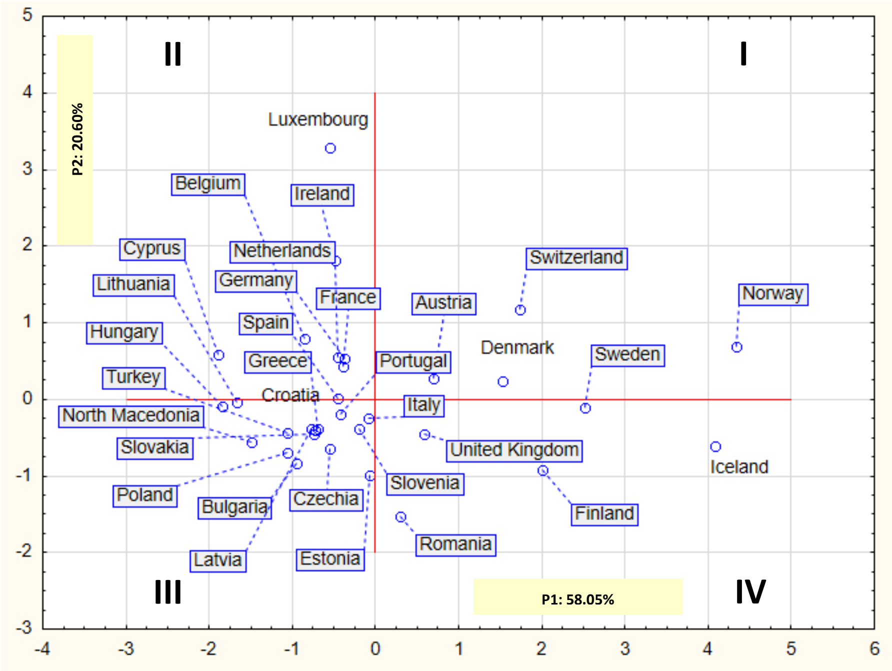
Source: own study based on: BP Statistical Review of World Energy (2021).

Figure 2. GDP per capita of studied European countries averaged over 2016–2020



Source: own study based on Eurostat data.

Figure 3. Principal component analysis for the European countries studied



Note: P1: component 1; P2: component 2