

Article

Management of Energy Sources and the Development Potential in the Energy Production Sector—A Comparison of EU Countries

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Abstract: Appropriate management of energy sources is one of the basic undertakings in the energy sector. Climate policy changes and the development of technologies enabling the acquisition of energy in a way to reduce the negative impact on the natural environment lead to diversity in the structure of the energy sources being used. Therefore, it is important to assess the impact of these changes on the development of energy sectors by particular countries. The article contains the analysis of various energy sources utilization by European Union (EU) countries and the assessment of the energy production sector potential, and the development of this potential in relation to changes in the energy sources structure. For this purpose, a multidimensional comparative analysis was used. The data for the analysis are derived from the Eurostat database for the years 2017 and 2019 for 28 EU countries and they concern the use of energy sources such as combustible fuels, coal and manufactured gases, natural gas, oil and petroleum products (excluding biofuel portion), hydro/hydropower, wind power, solar photovoltaic, nuclear fuels and other fuels n.e.c. As a result of the research, it was proved that in most EU countries the changes introduced in the structure of the use of various energy sources, according to EU climate policy, have a positive impact on the development of particular energy sectors.



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1. Introduction

A well-managed energy production sector is fundamental for building the economy of every developed country. Electricity may be produced with the use of various sources. The structure of electricity production in particular countries is dependent above all on the presence of the fuel resources or natural capabilities of producing the energy. Among the methods of producing the energy, one may distinguish conventional ones (based on the combustible fuels, in other words, non-renewable energy sources such as hard coal, brown coal, oil, natural gas) being unfortunately the very reason for extensive environmental pollution; nuclear ones—based on the use of uranium; and methods of producing energy from renewable energy sources (RES) such as water, wind and the sun. Obtaining national energy security to be understood as the ability to provide the energy of the agreeable price while constantly accessed to indispensable energy sources [1,2], is the rudimentary duty of governments, but considering the aspects of balanced development and environmental protection, it has proved to be the priority of the EU energy strategy [3]. Taking it into consideration, it is to be noted that the quantity of RES-produced energy is systematically growing in all European countries. Thus, the question arises: whether and how is the type of sources used for producing electricity related to the development potential of countries in the region?

The purpose of the article is the indication of sources, from which energy is produced in the energy sector of European Union (EU) member countries, as well as the analysis of

the development measures of the sector comprehended in the light of the management of diverse sources of the energy.

Therefore, the main hypothesis is the assumption that countries diversifying sources of energy are characterized with higher development potential in the energy production sector. The basis of the analysis was information covering the years of 2017 and 2019, which describes energy production from various sources in 28 EU countries obtained from the Eurostat database. The choice of such time span had been made upon the completeness of the data found in the public database.

2. The Change of Perception of Energy Sources—Literature Review

Individual countries are developing their own electricity supply systems for their consumers, bearing in mind the strategic importance of electricity for the functioning of each country. In most countries, oil and petroleum products and coal (hard and brown) are the basic fuels from which electricity is produced. In global energy production, one may distinguish certain phases associated with sources of its production. Until 1910, energy was produced mainly from regular biomass. In the years 1910–1965, the main source from which energy was obtained was coal (currently it occupies the second place in global energy production). However, the period between the second half of the 1960s until present times is characterized by the highest contribution of oil and petroleum products in energy production. Moreover, since the 1970s, the use of gas as a source of energy in the world has also been increasing (gas is currently the third largest source of energy) [4–6]. The contribution of RES is also growing—countries with appropriate conditions resulting from their geographical location produce a considerable portion of energy in hydroelectric power stations. Some European countries produce a significant proportion of their electricity in nuclear power plants. Nevertheless, the energy production sector is still one of the most environmentally damaging. Energy supply, including fuel production and processing and energy production, is the third sector in the EU among those contributing to air pollution [7]. This is the reason for the EU accepting one of the most stringent policies for environmental protection and pollution reduction of at least 32% by 2030, ensuring the EU a leadership position in the RES area in the future [8]. In addition, The European Green Deal, formulated at the end of 2019, points to the necessity of the EU region transforming into a modern, resource-efficient and competitive economy without net greenhouse gas emissions by 2050, assuming that economic growth will be independent of resource consumption [9]. All EU member states (MS) have recognized the importance of integrating RES in the energy sector in order to increase environmental protection, security and diversification of energy supply and to contribute to social development.

Undoubtedly, the subject related to energy management, including energy production, attracts the attention of many researchers. It is noteworthy that the number of studies corresponding to energy sources, which were produced in two periods: between 1996 and 2000 and between 2001 and 2005, according to the results of a search in the Science Direct database, oscillates in both cases at around 40,000. In the next five-year period of 2006–2010 the number of studies on the subject doubled (almost 80,000). However, the real boom of this subject has come in the last decade—in the period 2011–2015, the number of studies on energy sources reached 130,000, and from 2016 to the end of November 2020, more than 286,000 studies were undertaken. This is also linked to changes in environmental protection and the pressure to use renewable energy sources. The first such publications were as early as the 1960s, for instance the publication of J. McHale [10], but the actual beginning of interest in this subject dates back to the late 1970s [11–13]. It is worth adding that among about 130,000 RES publications found in the ScienceDirect database, published between 2001–2020, there are many studies concerning only developing or newly industrialised countries [14–17]. There are also many studies on the external costs of energy technologies in relation to the negative effects associated with electricity production at all stages of the technical process (the construction and the decommissioning of power stations, extraction and transport of energy resources, emission of pollutants) [18–22].

A number of studies have also addressed the relationship between specific economic activities such as energy production (including energy sources) and economic growth of respective countries [8,23,24]. Considering the literature related to the energy production sector, we can note a certain tendency: most of the current studies focus on the use of RES, RES-related technologies, their impact on the energy production sector, and their relation to various economic indicators. Among the few current studies that include analysis of the use of another energy sources as well, we can distinguish studies by Nong et al. [25] or Bogdanov et al. [26]. However, these authors do not study the impact of changes in the structure of these energy sources on the development potential of the energy sector itself, which is the subject of this article. Moreover, it can be noted that thematically compatible, available research on the energy production sector is mainly based on statistical methods of data analysis, as for example simple additive weighting (SAW) [27], technique for order of preference by similarity to ideal solution (TOPSIS) [28], data envelopment analysis (DEA) [29,30], the fully-modified least square (FMOLS) method [23] etc. Nevertheless, most of the studies in this field refer to a specific economy of a given country, and do not cover such a large group of countries as in the European Union. Therefore, by setting the goal to examine 27 (28 with the UK) EU member countries, a multidimensional comparative analysis has been selected, in particular the methods of linear ordering of objects and a ranking sensitivity analysis.

Considerations undertaken in this study concern the knowledge gap on the changes in the structure of the use of energy sources and the development potential of energy production from the perspective of EU countries.

3. Methodology

A thorough understanding of both complex and simple economic phenomena affecting the economic development of European Union countries, in terms of the volume of energy production through various energy sources, is possible due to thorough multidimensional analysis, which uses statistical methods. The examination of units in terms of complex phenomena, i.e., those described by means of several variables, does not allow drawing a simple conclusion which unit of measurement has the highest level of complex phenomena [31]. For this reason, certain methods from the area of multidimensional (comparative) statistical analysis are used, which enable the assessment of the differences of examined units due to a complex phenomenon and the ranking of the examined units in accordance to the level of a complex phenomenon.

When using multidimensional statistical analysis methods, it is necessary to know how the variables are divided in terms of features to-be-adapted. A distinction is made between stimulants (the increase of the variable value indicates an increase in the level of the complex phenomenon), destimulants (variables whose high values are undesirable from the perspective of the general specificity of the examined phenomenon), and neutrals (neutral variables whose deviation from the normal level are undesirable from the perspective of the general specificity of the examined phenomenon) [32].

Linear ordering methods, which constitute the basis of multidimensional comparative analysis, are widely used especially while assessing the diversity of objects in terms of the achieved level of development. The aim of grouping methods is to separate sets of similar elements in certain respects. It serves the purpose of determining the value of the function of a given criterion and finding such a shift between groups that would improve the value of the criterion function. Multidimensional comparative analysis provides an opportunity to examine a complex phenomenon (described by means of several variables—energy sources), which represents the development potential of the energy production sector in different EU countries. The vector of variables has been studied:

$$X = [X_1 \dots X_m], \quad (1)$$

where m —the number of variables. When using multidimensional comparative analysis methods in terms of the condition of separating the variables expressed in the same units

of measurement with similar orders of magnitude, it is recommended to normalise the variables in order to standardise both the units of measurement and the orders of magnitude of variables. A frequently used method of normalisation is standardisation, performed in accordance to the following scheme:

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{S_j}, \quad (i = 1, 2, \dots, n; j = 1, 2, \dots, m) \quad (2)$$

where the individual symbols mean:

n —the number of objects,

z_{ij} —the normalised value of X_j variable for the object,

$\bar{x}_j$ —the arithmetic average of X_j variable,

S_j —the standard deviation of X_j variable.

The phrase that allows objects to be compared to one another from the perspective of a complex phenomenon is the similarity defining that objects are the more similar to each other, the more similar the values of variables describing a given complex phenomenon are. Such perceived similarity in multidimensional comparison analysis is usually measured by the distance between objects, which assigns a single value to two objects. Therefore, the Euclidean distances of individual objects are to be determined in terms of the exemplar object, as expressed by the formula:

$$d_{i0} = \sqrt{\sum_{j=1}^m (z_{ij} - z_{0j})^2} \quad (i = 1, \dots, n) \quad (3)$$

whereby,

$$z_{0j} = \begin{cases} \max_i z_{ij} & \text{for stimulants} \\ \min_i z_{ij} & \text{for destimulants} \end{cases} \quad (4)$$

It was assumed that the level of influence of all variables on the analysed phenomenon is the same. Thus, the measure of the development for each object was estimated expressed by the scheme:

$$m_i = 1 - \frac{d_{i0}}{d_0} \quad (i = 1, \dots, n), \quad (5)$$

where d_0 means the distance between the pattern and the anti-developmental pattern expressed by the formula:

$$d_0 = \sqrt{\sum_{j=1}^m (z_{ij} - z_{-0j})^2} \quad (i = 1, \dots, n) \quad (6)$$

whereby:

$$z_{-0j} = \begin{cases} \min_i z_{ij} & \text{for stimulants} \\ \max_i z_{ij} & \text{for destimulants} \end{cases} \quad (7)$$

For a measure of the development described in such a manner, whose values are contained in the range $[0, 1]$, it is assumed that the higher its value, the higher the level of the examined phenomenon.

The article attempts to determine to what extent the management of the structure of energy sources affects the development potential of the energy sectors of the European Union countries. The analysis is also to indicate how the situation of individual countries is shaped in relation to the usage of different energy sources. For this purpose, the methods of numerical taxonomy were used as well as the methods of linear ordering of objects in particular. The analysis was made on the basis of statistical data available from Eurostat covering years 2017 and 2019.

4. A Measure of the Development of the Energy Sector of European Union Countries—Results of the Study

The study analysed the countries of the European Union in relation to producing energy from various energy sources. These countries differ from each other in a number of ways, but they all understand the necessity for effective management of energy sources in the context of the balanced development and the need to protect the environment. Methods of multidimensional data analysis were used. It was assumed that the use of energy sources can be expressed by a synthetic variable, which consists of the use of different types of energy fuel. The 27 countries of the European Union (Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden) and the United Kingdom were studied. In addition, these countries were compared in two periods—2017 and 2019, whereas the data from Eurostat were used for the analysis.

Table 1 presents the changes in the contribution of individual energy sources in 2019 compared to 2017 in EU countries.

Table 1. Percentage change in net energy production in European Union (EU) countries in 2019 compared to 2017 by the division to the energy source [GWh].

2019/2017	Combustible Fuels	Coal and Manufactured Gases	Natural gas	Oil and Petroleum Products (Excluding Biofuel Portion)	Hydro	Wind	Solar Photovoltaic	Nuclear Fuels and other Fuels n.e.c.	Total
Austria	99%	87%	104%	79%	106%	112%	-	-	103%
Belgium	106%	104%	111%	17%	82%	148%	122%	103%	109%
Bulgaria	91%	84%	112%	127%	111%	91%	107%	107%	95%
Croatia	99%	121%	83%	41%	108%	123%	98%	-	102%
Cyprus	101%	-	-	101%	-	113%	134%	-	102%
Czechia	96%	89%	158%	98%	105%	119%	105%	107%	98%
Denmark	82%	60%	91%	100%	105%	109%	122%	-	90%
Estonia	55%	-	-	-	61%	94%	-	-	57%
Finland	103%	89%	123%	128%	84%	125%	814%	106%	101%
France	91%	31%	100%	462%	115%	151%	128%	100%	102%
Germany	82%	71%	107%	87%	100%	118%	113%	98%	89%
Greece	86%	64%	105%	95%	100%	131%	99%	-	90%
Hungary	100%	82%	109%	57%	100%	96%	401%	101%	103%
Ireland	88%	16%	102%	592%	126%	126%	-	-	94%
Italy	94%	-	-	-	125%	115%	98%	-	100%
Latvia	138%	-	150%	-	48%	104%	-	-	99%
Lithuania	92%	-	87%	67%	79%	110%	113%	-	94%
Luxembourg	117%	-	81%	-	66%	117%	109%	-	84%
Malta	125%	-	*	33%	-	-	a	-	251%
Netherlands	101%	63%	132%	1142%	129%	107%	270%	115%	106%

Table 1. Cont.

2019/2017	Combustible Fuels	Coal and Manufactured Gases	Natural gas	Oil and Petroleum Products (Excluding Biofuel Portion)	Hydro	Wind	Solar Photovoltaic	Nuclear Fuels and other Fuels n.e.c.	Total
Poland	96%	90%	160%	-	87%	101%	443%	-	96%
Portugal	72%	37%	91%	95%	136%	112%	150%	-	82%
Romania	83%	79%	89%	58%	107%	91%	95%	98%	90%
Slovakia	119%	93%	241%	108%	95%	-	100%	102%	109%
Slovenia	93%	93%	113%	39%	111%	107%	95%	93%	97%
Spain	88%	28%	132%	91%	128%	114%	109%	100%	96%
Sweden	105%	66%	134%	110%	101%	115%	-	102%	103%
United Kingdom	95%	36%	101%	37%	86%	120%	111%	80%	95%

* means that in 2017 the country did not produce energy from the given source. - means that a given country does not produce energy from a given source in the researched period. a—means no possibility of comparison, because the value in 2017 is characterized by low reliability. Own elaboration on the basis of [33].

It was assumed that the level of use of various energy sources is fundamental for the development of the energy production sector in the individual European Union countries. The determination of the synthetic variable allowed the creation of a ranking of the studied countries in terms of the level of the use of a given energy source. The following variables were distinguished in the study:

- X_1 —net electricity generation from combustible fuels [GWh per capita]
- X_2 —net electricity generation from coal net electricity generation from combustible fuels and manufactured gases [GWh per capita]
- X_3 —net electricity generation from natural gas [GWh per capita]
- X_4 —net electricity generation from oil and petroleum products (excluding biofuel portion) [GWh per capita]
- X_5 —net electricity generation from hydro/hydropower [GWh per capita]
- X_6 —net electricity generation from wind power [GWh per capita]
- X_7 —net electricity generation from solar photovoltaic [GWh per capita]
- X_8 —net electricity generation from nuclear fuels and other fuels n.e.c. [GWh per capita].

In order to enlarge the comparability of data, the variables are given per capita, thus as intensity indicators.

All variables have the character of a stimulant. These variables create potential for the development of energy management in respective European Union countries. The results of linear ordering are presented in total for eight groups of variables—energy production through the use of various sources in the European Union countries in 2017 (Table 2) and 2019 (Table 3). Tables 2 and 3 present a ranking of countries (top ranked are the industries with the highest value of a measure of the development), which enabled the comparison to what extent individual countries produced energy with different sources.

By the analysis of data from 2017, the best conditions for economic development potential with regard to the management of energy sources are created by Finland obtaining the energy from various sources per capita. In the remaining countries, the conditions for the development are equally good, as shown by the high development measurement index—the result close to 1 (Table 2). The situation by the top three countries is similar in 2019, but Finland became the leader in the ranking of European Union countries. It

is noteworthy that Hungary has improved its developmental score in 2019 compared to 2017 quite significantly (from 26th place to 22nd—Table 3). In this case, there was an 3% increase in energy production, combined with significant changes in the structure of the sources used (the use of coal and oil and petroleum products as energy sources decreased by 18% and 43%, respectively; however, there was also a significant hike in the use of solar photovoltaic of over 400%). In both periods studied, Lithuania is the last-placed country in the ranking of countries presenting the results of the measure of the development perceived through the degree of energy production from various sources per capita, which is not surprising due to its relatively small areas and energy demand.

Table 2. The results of the linear order—the distance of objects from the development pattern and a measure of the development for energy production per capita in the European Union countries in 2017.

	2017	THE DISTANCE FROM THE PATTERN	A MEASURE OF THE DEVELOPMENT
1	Germany	8.562	0.9390
2	Finland	8.782	0.9374
3	Cyprus	9.023	0.9357
4	Greece	9.068	0.9354
5	Spain	9.217	0.9343
6	Netherlands	9.225	0.9343
7	Sweden	9.235	0.9342
8	Portugal	9.255	0.9341
9	Czechia	9.412	0.9329
10	Belgium	9.422	0.9329
11	Ireland	9.486	0.9324
12	United Kingdom	9.661	0.9312
13	Slovenia	9.672	0.9311
14	Austria	9.716	0.9308
15	Bulgaria	9.737	0.9306
16	Denmark	9.777	0.9303
17	France	10.127	0.9279
18	Italy	10.322	0.9265
19	Poland	10.323	0.9265
20	Luxembourg	10.491	0.9253
21	Romania	10.576	0.9247
22	Estonia	10.620	0.9243
23	Slovakia	10.635	0.9242
24	Latvia	10.737	0.9235
25	Croatia	10.790	0.9231
26	Hungary	10.849	0.9227
27	Malta	11.252	0.9198
28	Lithuania	11.341	0.9192

Table 3. The results of the linear order—the distance of objects from the development pattern and a measure of the development for energy production per capita in the European Union countries in 2019.

	2019	THE DISTANCE FROM THE PATTERN	A MEASURE OF THE DEVELOPMENT
1	Finland	8.534	0.9374
2	Germany	8.582	0.9371
3	Cyprus	8.871	0.9350
4	Netherlands	8.897	0.9348
5	Sweden	9.027	0.9338
6	Greece	9.056	0.9336
7	Belgium	9.072	0.9335
8	Czechia	9.214	0.9324
9	Spain	9.230	0.9323
10	Portugal	9.383	0.9312
11	Slovenia	9.458	0.9307
12	Austria	9.525	0.9302
13	Bulgaria	9.538	0.9301
14	Ireland	9.568	0.9299
15	United Kingdom	9.645	0.9293
16	Malta	9.764	0.9284
17	Denmark	9.824	0.9280
18	France	9.864	0.9277
19	Poland	10.104	0.9259
20	Italy	10.135	0.9257
21	Slovakia	10.317	0.9244
22	Hungary	10.465	0.9233
23	Luxembourg	10.494	0.9231
24	Romania	10.518	0.9229
25	Latvia	10.570	0.9226
26	Croatia	10.577	0.9225
27	Estonia	10.780	0.9210
28	Lithuania	11.217	0.9178

It is worth noting that in both 2017 and 2019, Germany and Finland were performing best, which means that they could serve as role models for other countries in terms of the development potential related to energy production per capita and management of the structure of energy sources. The other countries presented in the study also showed high values for a measure of the development in relation to the efficient management of the energy structure, and their Euclidean distances from the pattern are minor. The improvement in the position of Hungary in 2019 was also noted. Taking the result of the study into consideration, it is to be concluded that in many countries there was an area in energy management that needs to be improved.

Due to its energy policy, many European Union countries are particularly involved into the promotion and use of renewable energy sources. Thus, it was decided to analyze the ranking sensitivity to certain changes in the structure of the examined objects. The countries with the highest share of renewable energy in gross final energy consumption,

such as Sweden, Finland, Latvia and Austria were, therefore, excluded from the analysis. The results are presented in Table 4.

Table 4. A measure of the development for energy production in selected European Union countries in 2017 and 2019.

	Country	A MEASURE OF THE DEVELOPMENT 2019	Place in the Ranking 2019	A MEASURE OF THE DE- VELOPMENT 2017	Place in the Ranking 2017
1	Belgium	0.9342	2	0.9330	7
2	Bulgaria	0.9310	10	0.9309	11
3	Croatia	0.2242	21	0.9229	20
4	Cyprus	0.9328	7	0.9332	5
5	Czechia	0.9331	6	0.9331	6
6	Denmark	0.9268	14	0.9290	13
7	Estonia	0.9189	23	0.9224	21
8	France	0.9295	11	0.9289	14
10	Germany	0.9380	1	0.9394	1
11	Greece	0.9335	4	0.9348	2
12	Hungary	0.9221	22	0.9211	22
14	Ireland	0.9289	12	0.9312	10
16	Italy	0.9262	16	0.9261	15
17	Lithuania	0.9163	24	0.9179	23
18	Luxembourg	0.9235	19	0.9250	16
19	Malta	0.9268	15	0.9174	24
20	Netherlands	0.9337	3	0.9326	9
21	Poland	0.9241	18	0.9245	18
22	Portugal	0.9320	8	0.9341	4
23	Romania	0.9229	20	0.9244	19
25	Slovakia	0.9253	17	0.9248	17
26	Slovenia	0.9320	9	0.9327	8
27	Spain	0.9333	5	0.9346	3
28	United Kingdom	0.9287	13	0.9304	12

Excluding from the analysis countries with the highest value of use of renewable sources in energy production had little impact on the order of the EU countries according to the measure of development and the value of this measure itself. The measures of development for all countries still assumes values close to one, which proves that particular energy sources are used similarly to the development pattern.

5. Discussion

The application of multidimensional data analysis for the research made it possible to prepare a ranking of the EU countries in term of the use of various sources for the production of electricity. The result of this analysis can be used to develop both good practices by the use of energy sources, especially renewable ones, and sustainable energy development strategies. However, the linear ordering could only show the ranking of the analyzed countries according to the distinguished variables. Undoubtedly, an important

problem in the field of energy source management is examining the efficiency of countries in the context of electricity production. The DEA (data envelopment analysis) method is a universal method that does not require adopting to many limitations and assumptions in advance. It allows us to determine—on the basis of the objects recognized as the best—the efficiency limit (the limit of production possibilities). With the DEA method, it is possible to determine not only fully effective objects but also those that are not fully effective. This method is widely used in research in the field of energy management [27,34]. This method, however, goes beyond the purpose of the research adopted in the paper but is an indicator of future research by the authors.

The linear ordering methods used in the study have helped not only to identify the European Union countries which make the most efficient use of individual energy sources, but also to determine their similarity to the pattern. Analysing the level of the use of individual energy sources, it can be confirmed that the EU countries indeed implement environment protection policy accepted by the EU, by relying on the analyses or models for this sector [3,35–37]. However, the pace and scope of these changes varies in terms of each country and energy sources, as can be seen from the data presented in Table 1. Therefore, the question arises as to whether the EU countries will in fact implement the changes by 2050 [38].

6. Conclusions

The presented analysis concerns the development potential of the energy sector in individual EU countries. It has been assumed that all energy sources are stimulants for the development of the energy sector, which seems reasonable from a purely economic point of view in relation to natural resources possessed. However, taking into account the environmental factor and the costs associated with it, it is worth continuing the research towards defining certain variables as destimulants. Such variables could be non-renewable energy sources [39,40], the use of which is undesirable due to environmental costs and EU regulations [20,41–43].

In addition, we would like draw attention to the fact that there are many studies in the scientific literature on the impact of the energy sector on economic development, while this study aimed to identify the development potential of the energy sector itself, or rather the energy production sector, in the context of the management of the structure of energy sources. It has been proven that the change of the structure of the use of various energy sources influences the development of this sector.

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