Identification of diagnostic variables for research into the level of development of energy markets

Anna Manowska
Akademicka 2A, 44-100 Gliwice, The Silesian University of Technology, Poland
Anna.Manowska@polsl.pl

Abstract. The development of the economies of European countries depends on stable and permanent access to various energy sources such as oil, gas, and coal. Securing the certainty of the necessary minimum energy supply in each country is a basic condition for the energy security of the state and its citizens. The current status and the most probable scenario for the power industry sector shows that the global demand for power will increase between 2000 and 2030 at a rate of 1.8% per year. The energy market in the European Union is under the process of internal integration. Energy transformation requires changes in the structure of energy production in the energy balances of member states in order to achieve the assumed environmental goals. Monitoring the transformation process is a scientific problem in which taxonomic methods are used. The aim of the article is to identify diagnostic variables for comparative analysis of the level of development of energy markets in selected European Union member states. International Atomic Energy Agency United Nations Organizations present an original set of 41 indicators for sustainable energy development, which can be divided into groups such as indicators on energy resources, the efficiency of their use, environmental pollution during the exploitation of energy resource and energy production technologies, economic indicators, accessibility to energy for society, energy dependence. Based on forty-one indicators, the availability of data for testing was analyzed. Finally, diagnostic variables were selected for which the available data was collected from the Eurostat database and transformed to the level required in the research. The research results will present the level of development of the Polish energy market in relation to other countries and differences in this respect.

1. Introduction
Fossil fuels have become the foundation of civilization development, basically deciding the shape of the global economy [1]. Crude oil took a dominant position, which was included in energy use at the beginning of the 20th century, natural gas appeared in the 1930s, and water was used in the 1940s. The end of the sixties and seventies of the twentieth century was a flourishing nuclear power. To this day, despite the growing share of renewable energy sources, fossil fuels have retained an important position. World energy production is growing [2]. In 2018, there was a 2.8% increase above the historical trend, as shown in figure 1.
This increase was the result of energy production in the United States and China. In total, this increase was 54% in 2018. Key data on the increase in energy production in 2018 by individual fuels are as follows [4]:
- Crude oil: global production increased by 2% as a result of the exploration and extraction of shale in the United States, resulting in the largest annual growth in the US in history (from 1990 + 16.5%). Oil production in Russia, the Middle East (except Iran) and Africa continues to increase.
- Natural gas: + 5.2% fueled by the United States and Russia, two major global producers.
- Coal: + 1.9%, through the economy of China, the largest producer in the world.

In 2018, the share of fossil fuels in global energy consumption was as much as 79.70%, nuclear energy was only 2.20%, while renewable energy accounted for 18.10% [5], as shown in figure 2.
In 2018, global energy demand increased an estimated 2.3%, the greatest rise in a decade. This was due to strong global economic growth (3.7%) and to higher heating and cooling demand in some regions. China, the United States, and India together accounted for almost 70% of the total increase in demand. Due to a rise in fossil fuel consumption, global energy-related carbon dioxide (CO₂) emissions grew an estimated 1.7% during the year.

The energy structure of Poland is definitely different from other European Union countries due to the significant share of coal in electricity production [6-11], as shown in figure 3.

![Energy Consumption Pie Chart](image_url)

**Figure 2.** Final Energy Consumption, 2018 (own elaboration based on data from [5])

**Figure 3.** The structure of the EU energy mix (own elaboration based on data from [12])

The share of coal in the energy balance is 78%, and it is mostly mined domestically, while imports dominate in other EU countries. The Polish mining industry has been undergoing transformation since the beginning of the 1990s. Hard coal production fell from 177.4 million Mg in 1989 to 63.4 million Mg in 1994.
Mg in 2018. Despite a significant reduction in production capacity for almost three decades, Poland is by far the largest producer of hard coal in Europe.

The structure of the country's energy mix has also changed over the years, as shown in figure 4.

To a large extent, the change in the energy balance results from the volume of imported fuels. From 1980, fuel imports began to outstrip their exports. This was affected by a decrease in the share of coal and an increased demand for hydrocarbon fuels. In 1990, the share of coal in the energy mix was 76%, reducing its share to 47% in 2017-2018. Another reason is the EU climate policy and increasing the share of renewable energy sources in the country's energy structure.

![Figure 4. The structure of the Poland energy mix (own elaboration based on data from [4])](image)

The future and development of energy are one of the most important problems in both domestic and global politics. The accession of Poland to the European Union requires an intensified implementation of procedures to adjust the energy market to European standards. Limiting the use of fossil fuels in the energy sector results from new legal conditions related to the protection of the natural environment. These changes require the development of a new energy strategy, taking into account the limits of greenhouse gas emissions in the European Union and the requirements of the Community energy policy. Monitoring the transformation process is a scientific problem in which taxonomic methods are used. The aim of the article is to identify diagnostic variables for comparative analysis of the level of development of energy markets in selected European Union member states.

2. Methodology and Data

In this article was used principal component analysis (PCA) involves defining completely new variables (principal components) which are a linear combination of the observed (original) variables. An exact analysis of the principal components makes it possible to point to those original variables which have a big influence on the appearance of particular principal components, which are those variables which constitute a homogeneous group. A principal component is then a representative of that group. Subsequent components are mutually orthogonal (uncorrelated) and their number is lower than or equal to the number of original variables.
Each principal component explains a certain part of the variability of the original variables. They are, then, naturally based on such measures of variability as covariance (if the original variables are of similar size and are expressed in similar units) or correlation (if the assumptions necessary in order to use covariance are not fulfilled).

The input data is the matrix containing subsequent observations on the basis of which the main components (base vectors of the new space) will be determined. They are also returned as one matrix. The PCA algorithm consists of the following steps [13]:

- Determination of mean for rows
  \[ u[m] = \frac{1}{N} \sum_{n=1}^{N} X[m,n] \]  
  (1)
  the subsequent positions of the mean vector \( u \), therefore, store the average of the corresponding rows. Therefore, the average values of subsequent features are calculated for all observations.

- Calculating the deviation matrix
  \[ X'[i,j] = X[i,j] - u[i] \]  
  (2)
  this step consists in subtracting from the input matrix the means calculated in point I. From each element of the matrix we subtract the average for the row in which it is located:

- Determination of the covariance matrix
  \[ C = E[B \cdot B'] = \frac{1}{N} B \cdot B' \]  
  (3)
  Where:
  - \( E \) is the expected value
  - \( B \) is the deviation matrix. In the case when the values of the matrix \( B \) are real, the Hermitian conjugation (‘) used in the formula is identical to normal transposition.

- Calculation of eigenvalues of the covariance matrix
  \[ V^{-1}CV = D \]  
  (4)
  where \( D \) is the diagonal matrix of eigenvalues \( C \).

There is not one universal criterion for the selection of the number of principal components. For that reason, it is recommended to make the selection with the help of several methods [13]:

- The percentage of explained variance - The number of principal components to be assumed by the researcher depends on the extent to which they represent original variables, i.e. on the variance of original variables they explain. All principal components explain 100% of the variance of original variables. If the sum of the variances for a few initial components constitutes a large part of the total variance of original variables, then principal components can satisfactorily replace original variables. It is assumed that the variance should be reflected in principal components to the extent of over 80 percent.

- Kaiser criterion - According to the Kaiser criterion the principal components we want to leave for interpretation should have at least the same variance as any standardized original variable. As the variance of every standardized original variable equals 1, according to Kaiser criterion the important principal components are those the eigenvalue of which exceeds or is near value 1.

- Scree plot - The graph presents the pace of the decrease of eigenvalues, i.e. the percentage of explained variance.

The energy sector can be analysed by indicators proposed by The International Atomic Energy Agency (IAEA) [14]. In 2000–2001, a potential set of energy indicators for sustainable development was identified and the conceptual framework to define and classify these indicators was developed. In 2002, the original set of indicators and framework were refined. The indicators are classified according to the three major dimensions of sustainable development: social, economic, and environmental.
For the comparative analysis of the level of development of energy markets in selected European Union countries, data on the structure of the energy mix in the European Union countries in 2018 was used, as shown in Table 1.

**Table 1. Primary Energy: Consumption by fuel, 2018 [Mtoe]**

|          | Oil  | Natural Gas | Coal  | Nuclear energy | Hydro electric | Renewables |
|----------|------|-------------|-------|----------------|----------------|------------|
| Austria  | 13.4 | 7.5         | 2.9   | -              | 8.5            | 2.8        |
| Belgium  | 34.1 | 14.5        | 3.3   | 6.4            | 0.1            | 3.8        |
| Czech Republic | 10.6 | 6.9         | 15.7  | 6.8            | 0.4            | 1.7        |
| Finland  | 10.7 | 1.8         | 4.3   | 5.2            | 3.0            | 4.3        |
| France   | 78.9 | 36.7        | 8.4   | 93.5           | 14.5           | 10.6       |
| Germany  | 113.2| 75.9        | 66.4  | 17.2           | 3.8            | 47.3       |
| Greece   | 16.0 | 4.1         | 4.7   | -              | 1.3            | 2.4        |
| Hungary  | 8.8  | 8.3         | 2.2   | 3.6            | 0.1            | 0.8        |
| Italy    | 60.8 | 59.5        | 8.9   | -              | 10.4           | 14.9       |
| Netherlands | 40.9 | 30.7        | 8.2   | 0.8            | ^              | 4.2        |
| Norway   | 10.4 | 3.9         | 0.8   | -              | 31.3           | 0.9        |
| Poland   | 32.8 | 17.0        | 50.5  | -              | 0.4            | 4.4        |
| Portugal | 11.5 | 5.0         | 2.7   | -              | 2.8            | 3.9        |
| Romania  | 10.2 | 9.3         | 5.3   | 2.6            | 4.0            | 2.0        |
| Spain    | 66.6 | 27.1        | 11.1  | 12.6           | 8.0            | 16.0       |
| Sweden   | 14.8 | 0.7         | 2.0   | 15.5           | 14.0           | 6.6        |
| Switzerland | 10.5 | 2.6         | 0.1   | 5.8            | 7.9            | 0.9        |
| Turkey   | 48.6 | 40.7        | 42.3  | -              | 13.5           | 8.5        |
| Ukraine  | 9.6  | 26.3        | 26.2  | 19.1           | 2.2            | 0.6        |
| United Kingdom | 77.0 | 67.8        | 7.6   | 14.7           | 1.2            | 23.9       |
| Other Europe | 62.4 | 25.9        | 33.6  | 8.3            | 17.9           | 11.7       |

Source: own elaboration based on: Eurostat [15]

3. Results and discussion

Principal component analysis (PCA) includes the observation described by many variables that are correlated with each other. To this end, a correlation matrix should be determined of energy mixes of EU countries. The results of the analysis are shown in Table 2.

**Table 2. Correlation matrix, 2018**

|          | Oil   | Natural Gas | Coal  | Nuclear energy | Hydro electric | Renewables |
|----------|-------|-------------|-------|----------------|----------------|------------|
| Oil      | 1,00  | 0.89        | 0.55  | 0.42           | 0.08           | 0.89       |
| Natural Gas | 0.89 | 1.00        | 0.54  | 0.25           | -0.05          | 0.84       |
| Coal     | 0.55  | 0.54        | 1.00  | 0.01           | -0.06          | 0.55       |
| Nuclear energy | 0.43 | 0.25        | 0.01  | 1.00           | 0.18           | 0.21       |
| Hydro electric | 0.08 | -0.05       | -0.06 | 0.18           | 1.00           | -0.02      |
| Renewables | 0.89 | 0.84        | 0.59  | 0.21           | -0.02          | 1.00       |

Source: own elaboration
Correlation of variables is the basis for performing PCA analysis. Table 2 shows that there is a strong correlation between natural gas, oil, coal, and renewables variables. This confirms that PCA analysis can be based on a correlation matrix. The eigenvalues of the main factors are shown in table 3.

**Table 3.** PCA - eigenvalues (correlations for 2017), sum of variances 6.0000

| eigenvalues | % of total variance | cumulative eigenvalues | Cumulative% |
|-------------|---------------------|------------------------|-------------|
| 1           | 4,342889            | 72,38148               | 72,38148    |
| 2           | 1,272055            | 21,20091               | 5,614944    |
|             |                     |                        | 93,58239    |

Source: own elaboration

The correlation-based PCA analysis is performed on standardized variables. The variance of each variable is equal to 1, and the total variance is equal to the number of variables included in the analysis, therefore the cumulative eigenvalue is 6. Guided by the Kaiser criterion, select those components that explain more than the average own value - equal in this case 1. This criterion meets two components. They explain over 9% of the total volatility. This is also confirmed by the scree plot shown in figure 5.

![Figure 5. Scree plot (own elaboration)](image)

The PCA analysis was made on the basis of a correlation matrix, so the factor coordinates of the variables and the correlation of factors and base variables are the same. The factor coordinates of the variables are shown in table 4.
Table 4. Factor loadings, 2018

| Variable        | Number | Factor 1    | Factor 2    |
|-----------------|--------|-------------|-------------|
| Oil             | 3      | 0.462370    | 0.157216    |
| Natural Gas     | 4      | 0.463978    | 0.056573    |
| Coal            | 5      | 0.405564    | -0.346065   |
| Nuclear energy  | 6      | -0.070170   | 0.872886    |
| Hydro electric  | 7      | -0.427792   | -0.296215   |
| Renewables      | 8      | 0.467469    | -0.051462   |

Source: own elaboration

From table 4 and figure 6 it can be seen that factor number 1 explains about 73%, factor number 2 explains about 21% of the total variation. Analysing loads of individual variables with the first factor, it can be seen that it reflects fossil fuels in energy mixes and renewable energy sources, while the second factor is associated with nuclear energy and hydroelectric.

4. Conclusions
The article describes the use of principal component analysis (PCA) to identify diagnostic variables to examine the level of development of energy markets. The structure of European Union energy mixes depends on the state and possibilities of using energy raw materials, determining the degree of fuel diversification, dependence on imports, and self-sufficiency. The level of natural gas, oil, coal, renewables, nuclear energy, and hydroelectric consumption was used to identify the level of development of energy markets. Two factors were obtained from the PCA analysis that could be used
to reduce the set of variables to compare energy markets. The first factor is related to fossil fuels and renewable energy, and the second factor is related to nuclear energy and hydroelectric. These factors have distinguished four groups of energy mixes (figure 6), depending on the dominant fuel. An energy mix based on nuclear energy is found in France. In 2018, consumption was 93.5 Mtoe. Norway is the only country where hydroelectric consumption was at 31.3 Mtoe. This value significantly differs from other energy sources. Poland is a country, where coal prevails in the energy sector. In 2018, 50.5 Mtoe was used. In the remaining analyzed countries, the energy mix is based mainly on gas, oil, and renewable energy sources. Those are Austria, Belgium, Czech Republic, Finland, Germany, Greece, Hungary, Italy, Netherlands, Portugal, Romania, Spain, Sweden, Switzerland, Turkey, Ukraine, and United Kingdom. Trends in global energy have a significant impact on the process of structural changes in the energy sector of the European Union, including Poland. The changes in the energy sector result primarily from the United Nations Conference Findings on Climate Change and legal regulations adopted by the EU Member States [16, 17]. The process of transformation in the energy system is already visible in the presented analysis. However, Poland is one of the countries that still need to transform the energy mix. Due to high investment costs, this process must be spread over a long time perspective, hence coal as energy fuel in Poland will continue to be the dominant fuel in the coming years.

Acknowledgment(s)
The work was elaborated in frames of the statutory research 06/030/RG3/0054.

References
[1] M. Kaliski, and D. Staśko, “Bezpieczeństwo energetyczne w gospodarce paliwowej Polski”. Publishing house of the Institute of Mineral Materials and Energy PAN. Kraków 2006 (in Polish).
[2] A. Manowska, and A. Nowrot, “The importance of heat emission caused by global energy production in terms of climate impact”. Energies, vol. 12 iss. 16, 1-12. 2019. https://doi.org/10.3390/en12163069.
[3] BP Statistical Review of World Energy [Online] 2019 Available at: www.bp.com.
[4] Enterdata, Global Energy Statistical Yearbook [Online] 2019 Available at: https://yearbook.enerdata.net/
[5] REN21, Renewables 2019. Global Status Report, [Online] 2019 Available at: https://www.ren21.net/.
[6] B. Kowal, and A. Kustra, “Sustainability reporting in the energy sector”, E3S Web of Conferences, 10, 00129. 2016.
[7] R. Ranosz, “Mining and its importance in the global economy”. Mineral Resources Management 30 (1), 5-20. http://doi.org/10.2478/gospo-2014-0003, 2014.
[8] B. Kowal, R. Ranosz, M. Karkula, and D. Kowal, „Process Management in Hard Coal Mining Companies”. Journal of the Polish Mineral Engineering Society, iss. 2 (42), 111-116, 2018. http://doi.org/10.29227/IM-2018-02-14.
[9] A. Bluszcz, “The emissivity and energy intensity in EU countries - consequences for the Polish economy”, Conference proceedings Energy and clean technologies. Recycling, air pollution and climate change. STEF92 vol. 18, iss. 4.2, 631-638. 2018 Sofia. https://doi.org/10.5593/sgem2018/4.2/S19.081.
[10] A. Bluszcz, “European Economies in terms of energy dependence”. Quality and Quantity, vol.51. no. 4 1531-1548. 2017. https://doi.org/1007/s11135-016-0350-1.
[11] A. Bluszcz, “Classification of the European Union member states according to the relative level of sustainable development” Quality and Quantity, vol. 50. iss. 6. pp. 2591-2605, 2016. DOI 10.1007/s11135-015-0278-x.
[12] Eurocoa, the voice of coal in Europe [Online] Available at: https://euracoal.eu/euracoal/.
[13] StatSoft: Electronic Statistics Textbook, [Online] Available at: https://www.statsoft.pl/textbook.
[14] IAEA and UNDESA, Energy Indicators for Sustainable Development Guidelines and
Methodologies. International Atomic Energy Agency, United Nations Department of Economic and Social Affairs, International Energy Agency, Eurostat And European Environment Agency, 2007.

[15] European Statistics Eurostat, [Online] Available at: https://ec.europa.eu/Eurostat.

[16] A. Manowska, “An Analysis of Coal Products Quality with Reference to Environmental Regulations of the European Union”. 21st International Scientific Conference“ Enterprise and Competitive Environment”. Brno 2018.

[17] A. Manowska. “Forecast to determine a development strategy for the mining sector”. 18th International Multidisciplinary Scientific GeoConference. SGEM 2018, 2 July - 8 July 2018, Albena, Bulgaria. Conference proceedings. Vol. 18, Ecology, economics, education and legislation. Iss. 5.3, Environmental economics. 967-974, 2018.