Analysing the development of renewable energy sources in European countries

Tatsiana Zoryna[1,2 *] and *Angelina* Matyushenko [2]

[1]Institute of Power Engineering, National Academy of Sciences of Belarus, 15 Akademičnaja Street, 2 building, 220072, Minsk, Republic of Belarus
[2]Faculty of Economics, Belarusian State University, 4 Niezaliežnasci Avenue, 220030, Minsk, Republic of Belarus

Abstract. This article investigates different types of electricity generation in European countries. The authors examined the trends of renewable electricity generation in Northern, Southern, Western and Eastern Europe. A cluster analysis was performed based on the factors that may predetermine the possibility of using different types of electricity generation: the level of economic development, the amount of air pollutant emissions and the level of energy reserves. Multiple discriminant analysis was used to test the hypothesis that each cluster is characterised by a specific direction. The dependent variable was the country's membership in the clusters, and the independent variables were the types of electricity generation used by the countries: thermal power generation (oil refinery products, gas, coal), nuclear power, hydropower, wind power, solar power, and bioenergy.

1 Introduction

Nowadays, renewable energy sources are becoming increasingly important in electricity generation, not only due to the exhaustion of natural resources, such as oil refinery products, gas, coal, but also due to significant changes in the environment and climate. It is also worth considering the economic factor: for countries that are not endowed with their own natural resources, the cost of generating electricity is many times higher due to the purchase of natural resources from countries that have mineral resources [1, 2, 3].

2 Analysis of electricity production from renewable sources

The authors examined changes in electricity production from renewable sources in 39 European countries. The countries of Northern Europe include: Denmark, Estonia, Finland, Iceland, Ireland, Latvia, Lithuania, Norway, Sweden, United Kingdom; Southern – Albania, Bosnia and Herzegovina, Croatia, Greece, Italy, Malta, Montenegro, North Macedonia, Portugal, Serbia, Slovenia, Spain; Western – Austria, Belgium, France, Germany,

* Corresponding author: tanyazorina@tut.by

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Luxembourg, Netherlands, Switzerland; Eastern – Belarus, Bulgaria, Czech Republic, Hungary, Moldova, Poland, Romania, Russia, Slovakia, Ukraine.

In 2020, the indicator increased by 80 % compared to 2005. In Northern Europe, electricity generation increased 1.67 times over the same period (fig.1). Hydropower accounted for the bulk of generation, while wind power expanded 12.25 times in 15 years. Tide, wave and ocean energies are not widespread in the Nordic countries.

The situation is quite different in Southern Europe (fig. 2). In 2020, 48 % are hydropower, 31.5 % are wind power (3.5-fold growth since 2005), 16.5 % are solar power (573-fold increase), 4 % are geothermal (2-fold increase).

Electricity generation in Western Europe is as follows: small fluctuations in hydro, tide, wave, ocean generation have not significantly changed the indicator, geothermal electricity has grown 182 times and solar electricity 58 times from 2005 to 2020 (fig. 3).

Hydropower is mainly concentrated in Eastern European countries (fig. 4). Electricity generation through solar energy increased 3-fold from 2010 to 2020. The increase in electricity generation is characteristic of wind power over a period of 15 years, the indicator increased 138 times. Geothermal energy has not changed significantly. Tide, wave, ocean energies are not widespread in Eastern Europe.

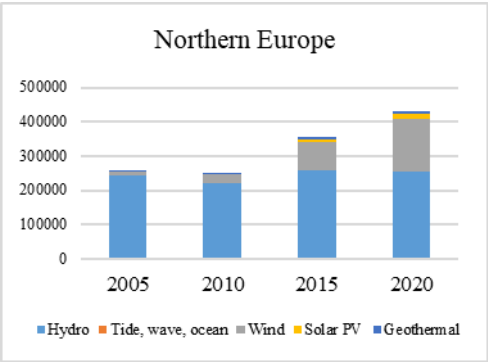

Fig 1. Types of electricity generation sources in Northern Europe 2005 to 2020 [4].

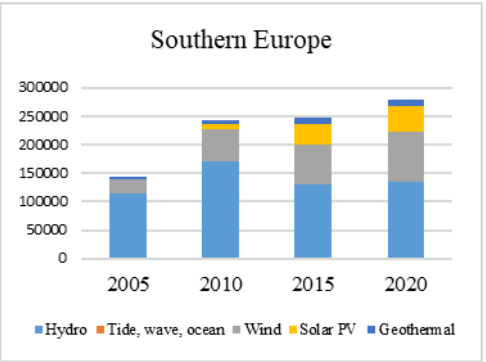

Fig 2. Types of electricity generation sources in Southern Europe 2005 to 2020 [4].

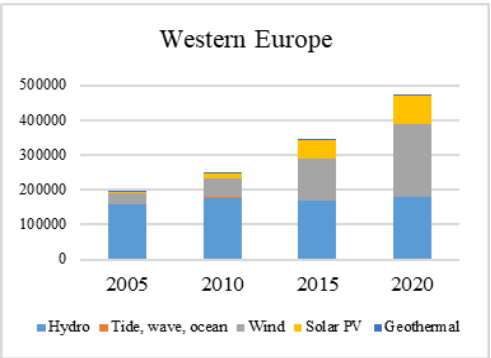

Fig 3. Types of electricity generation sources in Western Europe 2005 to 2020 [4].

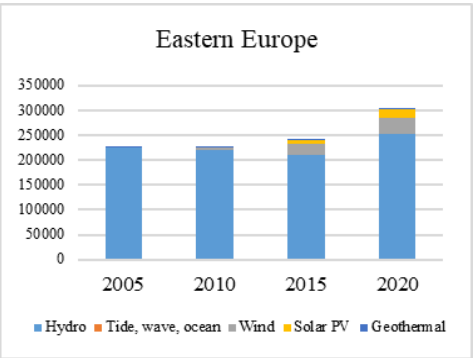

Fig 4. Types of electricity generation sources in Eastern Europe 2005 to 2020 [4].

To further investigate the development of renewable energy sources in European countries, the authors hypothesised that there are groups of countries with a similar level of development of certain factors for which the use of certain types of electricity generation is most characteristic.

The factors that predetermine the possibility of using a particular type of power generation include the following:

1) the level of economic development (indicator - GDP per capita in thousand US dollars);
2) the amount of pollutant emissions into the atmosphere (indicator - CO2 emissions in tonnes per capita);
3) the level of energy resources reserves (indicator - the share of own fossil energy resources (coal, natural gas and oil) in electricity generation in %).

To analyse these indicators, information on 39 European countries for 2010 was collected. The sources were statistical data of the World Bank [5], IEA [4], World-Statistics.org [6].

It is worth noting that the authors made calculations for 2010 based on a long-time lag between the establishment and start-up of any of the power plants, influenced by various factors.

The method of hierarchical cluster analysis was used to identify groups of countries with a similar level of development of the above factors. The Euclidean distance squared was chosen as a measure of similarity. The Euclidean distance square is the sum of squares of differences in values for each variable. It is the most used similarity measure. Based on the analysis of agglomeration steps, it was determined that 3 clusters were optimal for classifying this population. The SPSS software package was used to divide the countries into clusters [7].

In order to simplify the interpretation of the results, the quantitative characteristics of the factors used in the analysis were divided into 3 categories characterising low, medium and high value (Table 1). The interval for each series was determined on the basis of the variation spread. The upper boundary of the low category was calculated considering the minimum value of the trait and the given interval. The upper boundary of the middle category was determined based on the specified interval and the value of the upper boundary of the lower category.

Table 1. Classification characteristics of countries.

Characteristics	Level of economic development (GDP per capita, USD)	Amount of pollutant emissions into the atmosphere (CO_2 emissions tonnes per capita)	Level of energy resources reserves (share of own fossil energy resources (coal, natural gas and oil) utilisation in electricity generation), %
Low	Less 38586,53	Less 8,33	Less 33,33
Medium	38586-74736,27	8,33-15,06	33,33-66,67
High	Over 74736,27	Over 15,06	Over 66,67

The clustering results are presented in Table 2.

Multiple discriminant analysis was used to test the hypothesis that there are directions characteristic of each cluster. The dependent variable was the country's membership in the clusters, and the predictors (independent variables) were the types of electricity generation used by the countries: thermal power generation (oil refinery products, gas, coal), nuclear power, hydropower, wind power, solar power, and bioenergy.

The purpose of the discriminant analysis was to identify correspondences between clusters identified on the basis of country characteristics (level of economic development; level of air pollutant emissions; level of energy reserves) and groups of countries identified on the basis of discriminant functions by the set of electricity generation sources they use. The coincidence of clusters and discriminant groups will allow us to conclude that there is a

relationship between the characteristics of countries and the development of renewable sources of electricity generation.

Table 2. Characteristics of clusters.

Cluster	Characteristics			Number of observations	Countries
	Level of economic development	Amount of pollutant emissions into the atmosphere	Level of energy resources reserves		
1	low	low or medium	mostly high	23	Albania, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Moldova, Montenegro, North Macedonia, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Ukraine
2	low or medium	low or medium	mostly low	13	Austria, Belgium. Denmark, Finland, France, Germany, Iceland, Ireland, Italy, Netherlands, Spain, Sweden, United Kingdom
3	high	low or high	mostly low	3	Luxembourg, Norway, Switzerland

A direct method was used to build the model, which implies the inclusion of all predictors in the model. Discriminant analysis was performed using the SPSS software package. As a result, 2 discriminant functions were obtained [8].

Based on the results of the discriminant analysis, the countries were classified into 3 groups. The composition of discriminant groups is presented in Table 3 (plus means that there is a type of electricity generation in one the countries, minus means that there is none).

Table 3. Characteristics of discriminant groups.

Cluster	Types of electricity generation								Number of observations	Countries
	Thermal power generation (refined products)	Thermal power generation (gas)	Thermal power generation (coal)	Nuclear power	Hydropower	Wind power	Solar power	Bioenergy		
1	+ or –	+ or –	+ or –	+ or –	+ or –	+ or –	+ or –	+ or –	17	Albania, Bosnia and Herzegovina, Bulgaria, Czech Republic, France, Germany, Latvia, Lithuania, Malta, Moldova, North Macedonia, Poland, Romania, Russia, Serbia, Slovenia, Ukraine
2	+ or –	+ or –	–	+ or –	+	+	+ or –	+ or –	17	Austria, Belarus, Belgium, Croatia, Denmark, Estonia, Hungary, Iceland, Italy, Montenegro, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, United Kingdom

3	–	+	+ or –	+ or –	+	+	+	+	5	Finland, Greece, Ireland, Luxembourg, Switzerland

Comparing the correlation of countries by cluster and discriminant groups (Tables 2 and 3), we can conclude that the results of the cluster and discriminant analyses do not match perfectly. Thus, not all countries with similar characteristics use the same types of electricity generation.

Table 4 was compiled to compare the predicted group membership of clusters.

Table 4. Predicted group membership of clusters in %.

Cluster	Predicted group membership		
	1	2	3
1	65,2	30,4	4,3
2	15,4	69,2	15,4
3	0	33,3	66,7

Table 4 shows that in cluster 1, 65.2 % of countries use typical types of electricity generation for their cluster, 30.4 % of cluster 1 countries use directions typical for cluster 2, and 4.3 % use directions typical for cluster 3.

In cluster 2, 69.2 % of countries in cluster 1 use standard types of electricity generation, while 15.4 % of countries in cluster 1 and cluster 3 use more appropriate types of generation, respectively.

66.7 % of countries in cluster 2 use standard types of electricity generation for their cluster, 33.3 % of countries use directions more typical for cluster 2.

3 Conclusion

Thus, renewable energy has an extremely high potential on the European continent. Due to the realization of increasing environmental and climate challenges, European society is increasing renewable electricity generation. Cluster and discriminant analysis showed that only 66.7 per cent of European countries use types of electricity generation that are specific to their cluster, i.e. directions that correspond to the level of economic development of the country, taking into account the size of pollutant emissions into the atmosphere and the level of energy reserves. It is also worth noting that countries with a higher level of GDP per capita are more active in the transition to renewable electricity.

References

1. A. Gorji, I. Martek, Renewable energy policy and deployment of renewable energy technologies: The role of resource curse, *Environmental Science and Pollution Research*, **30**. 1-19. DOI: 10.1007/s11356-023-28851-9. (2023)
2. T. Rokicki, G. Koszela, L. Ochnio, A. Perkowska, P. Bórawski, A. Bełdycka-Bórawska, B. Gradziuk, P. Gradziuk, S. Agnieszka, A. Szeberényi, M. Dzikuć, Changes in the production of energy from renewable sources in the countries of Central and Eastern Europe, *Frontiers in Energy Research*, **10**. DOI: 10.3389/fenrg.2022.993547. (2022)
3. T. Zoryna, Sustainable energy development: countries and strategies, Sustainable Energy Policy and Strategies for Europe : 14th International Association for Energy

Economics European Conf., Rome, 28–31 Oct. 2014, Associazione Italiana Economisti dell'energia ; ed. C. A. Bollino. Rome, 2014. P. 278–281.

4. International Energy Agency, URL: http://www.iea.org/ (accessed 08/24/23)
5. The World Bank, URL: http://data.worldbank.org/ (accessed 08/24/23)
6. World Statistics, URL: http://world-statistics.org/ (accessed 08/24/23)
7. Harameen, Huzaifa Mohammed Adam & G., Akman, A Cluster Analysis of Renewable Electricity Generation Policies in Asian Region Countries Using SPSS Software. *Uluslararası Yönetim Akademisi Dergisi*. **6**. DOI: 10.33712/mana.1104853. (2023)
8. T. Ramayah, A. Noor, A-H Hasliza, R. Siti, M.Z. Siti, L. May Chiun, Discriminant analysis: An illustrated example. *African Journal of Business Management*. **4**. 1654-1667. (2010)