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AN EVALUATION OF THE IMPLEMENTATION OF SUSTAINABLE DEVELOPMENT GOAL 7 IN EUROPEAN UNION COUNTRIES IN 2013 AND 2022 USING THE WARD'S METHOD

The aim of this article is to assess the implementation of Sustainable Development Goal 7 by European Union countries in 2013 and 2022. This objective is achieved by grouping EU countries using one of the methods belonging to hierarchical agglomeration – the Ward method. The results of this study show that, in 2022, compared with 2013, the gap between the EU countries in terms of meeting Sustainable Development Goal 7 narrowed. Northern European countries are the best performers in the implementation of SDG7, and their situation continues to improve. In contrast, the southern and eastern European countries, despite the progress made, are still far behind in the implementation of this goal. Separated by the Ward method, the groups of countries with similar levels of SDG7 implementation have certain characteristics that are useful in monitoring the progress of individual countries and in implementing appropriate policies.

Keywords: SDG7, European Union countries, Ward's method.

1. INTRODUCTION

Sustainable development has been the subject of scientific research, economic analysis or public debate for many years and the issue is still relevant today. Sustainable development is currently the most popular development concept, broadly accepted worldwide.

The concept of sustainable development is very complex and is therefore defined differently in the literature. The most common assumption is that sustainable development

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implies the management of natural resources, taking into account their depletion and bringing them into use according to social and economic needs (Roszkowska et.al., 2014).

It is important to stress the great importance of sustainable development for the economies of individual countries as well as societies. Sustainable development is development that meets the needs of people today without compromising the ability of future generations to satisfy their. It is based on a comprehensive approach that combines economic, social and environmental issues in a way that ensures that they reinforce each other (Raczkowska et.al., 2021).

The concept of sustainable development has evolved over the years and the current 2030 Agenda for Sustainable Development (Transforming Our World: the 2030 Agenda for Sustainable Development) is a programme of action that sets out a model for sustainable development at a global level. The Agenda contains 17 Sustainable Development Goals (SDGs), divided into 169 targets and 304 indicators, to make people's lives better, healthier and safer in 2030, both socially, environmentally and economically (Grzebyk, Stec, 2015). These goals can be implemented worldwide, taking into account the different conditions of individual countries, their capacities and levels of development, and their compatibility with national strategies and priorities.

It is emphasised that the individual Sustainable Development Goals are closely interlinked. The achievement of one of the Sustainable Development Goals may hinder or even prevent the achievement of the others (Raczkowska et.al., 2021).

Despite the fact that the 2030 Agenda is more expansive than the previous Millennium Development Goals, it is sometimes seen as a utopian, ambitious declaration that does not take into account many of the problems facing the world today: refugees, religious fundamentalism or the system of the global economy supporting the growth of inequality (Szymczak, 2018).

The European Union is therefore working to implement the Sustainable Development Goals in its Member States, as reflected in the directives it adopts.

Energy plays a significant role in sustainable development initiatives, hence the aim of this article is to assess the implementation of Sustainable Development Goal 7 by EU countries in selected years, i.e. 2013 and 2022. This objective was attempted by grouping EU countries into similar groups using Ward's method.

The article poses the following research questions:

- Which EU countries have similar levels of achievement of Sustainable Development Goal 7 in the years under review?
- What are the characteristics of groups of countries with similar levels of achievement of Sustainable Development Goal 7?
- What is the consistency of the grouping results in the years studied?

2. LITERATURE REVIEW

The 2030 Agenda implies the active involvement of the European Union in its implementation, including usage of analytical and scientific capacities to forecast future risks and challenges. It is also a declaration of commitment to a Europe that is ready to share its experience and knowledge with other parts of the world, supporting other countries on the road to sustainable development, to develop or adapt technology to their needs taking into account the specificities of their economy, society and culture, involving all stakeholders in the process (Latoszek, 2017).

The Agenda's sustainable development goals are intended to prevent climate change, poverty, inequality, discrimination, lack of access to natural resources and war (Sachs,et.al., 2022).

Among the 17 Sustainable Development Goals (SDGs) of the 2030 Agenda, SDG 7 occupies an important position. Under Goal 7, the European Union has adopted the following tasks (United Nations. Goal 7., 2022):

7.1 By 2030, ensure universal access to affordable, reliable and modern energy services.

7.2 By 2030, increase substantially the share of renewable energy in the global energy mix.

7.3 By 2030, double the global rate of improvement in energy efficiency.

7.A By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.

7.B By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed ones, small island developing States and landlocked developing countries, in accordance with their respective programmes of support.

SDG7 emphasises the importance of energy security to guarantee affordable and reliable energy access for everyone.

Energy security is defined as the accessibility and availability of energy at affordable prices for everyone (Luty et.al., 2023).

As the world's population grows, the demand for energy is increasing rapidly, and with it the importance of ensuring that energy production and consumption are sustainable.

The energy sector is responsible for more than 75% of greenhouse gas emissions, covering a wide range of sources from traditional fossil fuels to renewable energy sources. Therefore, the energy transition should be inextricably linked to reducing GHG emissions by phasing out fossil fuels and replacing them with renewable energy sources on a global scale (Diaconescu et.al., 2024).

The intersection of energy and sustainable development has become a key arena in the global pursuit of the Sustainable Development Goals. In a world marked by growing concerns about environmental degradation, climate change and socio-economic inequality, understanding the multifaceted contribution of the energy sector to sustainable development has become imperative (Carvalho, Santos, 2024).

Energy is an essential element not only for sustaining economic growth and the survival of humanity, but also in terms of contributing to the stability of political, economic and social processes of individual countries (Luty et.al., 2023).

The implementation of SDG7 should cover three aspects: environmental, economic and social.

In the environmental aspect, achieving Goal 7 will enable consumers to have access to clean energy without emitting harmful substances that negatively affect the environment. The economic aspect is primarily about ensuring an uninterrupted supply of energy in the required quantity, time, place and at an affordable price. Without this, economic development is impossible. In the social aspect, the achievement of SDG7 is to ensure the elimination of energy poverty. Access to energy affects the quality of life of society and access to education and healthcare (Rybak et.al., 2024).

Fitting into the current research on SDG7 and analysing the literature on the subject, one notices a continuous increased interest in this issue. In recent years (2019–2024),

several hundred articles have been written on this topic[4]. Research directions revolve around several main issues, which include: assessing the level of progress in the implementation of this target in the EU using various statistical methods (Bączkiewicz, Wątróbski, 2022; Czerwińska et.al., 2023; Dmytrów et.al, 2022), determining the relationship between SDG7 and renewable energy consumption in EU countries (Firlej, Stanuch, 2023), the importance of effective economic policies in achieving this target (Zarghami, 2025), assessing energy efficiency (Zhang et.al., 2024) and productivity within a circular economy (Campoli, 2024), exploring the role of green innovation technologies, economic progress and urbanisation on energy demand (Xing, 2024).

The research results presented show that the scope is quite broad, but there is a lack of analysis on the usage of country grouping methods to assess progress in SDG7 implementation.

3. SELECTION OF DIAGNOSTIC VARIABLES AND ASSUMPTIONS OF THE RESEARCH METHOD

Ward's method was used to assess the achievement of the EU countries' Sustainable Development Goal 7 in 2013 and 2022.

The initial step in the application of clustering methods is to adequately prepare the variables used in the study by checking their level of variability and correlation. The assessment of variability usually adopts the classic coefficient of variation based on the arithmetic mean and standard deviation. Variables for which the coefficient of variation is lower or equal to 0.10 are removed from the set of potential diagnostic variables, while the correlation of variables can be assessed using, for example, the inverse correlation matrix method of Malina and Zelias (1998). After statistical verification of the variables, the so-called diagnostic variables remain in the set of variables.

As the diagnostic variables are expressed in different units, their normalisation is carried out using formulas:

For stimulants

$$z_{ij} = \frac{x_{ij} - \min\limits_{i}\{x_{ij}\}}{R_j} \tag{1}$$

For destimulants

$$z_{ij} = \frac{\max\limits_{i}\{x_{ij}\} - x_{ij}}{R_j} \tag{2}$$

It should be added that the minimum value, maximum value and spread were calculated simultaneously for both years under study.

Ward's method, among others, can be used to group countries with similar levels of implementation of Sustainable Development Goal 7. It is characterised by high efficiency, understood as the ability to correctly identify the real structure of objects in a multidimensional classification space (Sokolowski, 1992).

[4] Data based on bibliometric analysis of the Scopus database conducted 11.11.2024 considering keyword: SDG 7.

Ward's method is one of the hierarchical agglomerative methods. All such procedures can be described by the so-called central agglomerative procedure (Grabinski, 2003; Lance, Williams, 1967; Ward, 1963).

The starting point is a matrix D of distances d_{ij} between classified objects O_1 , O_2 ,...,O_n. A taxonomic distance is the distance between points in a multidimensional space. In order to measure the distance between points, a specific metric must first be adopted. In practice, the Euclidean distance of the form (Nowak, 1990) is most commonly used:

$$d_{ik} = \sqrt{\sum_{j=1}^{m}\left(z_{ij} - z_{kj}\right)^2} \quad (i,k = 1,2,...,n). \tag{3}$$

By calculating the distances between the highlighted objects, a distance matrix is obtained

$$D = \begin{bmatrix} 0 & d_{12} & \dots & d_{1n} \\ d_{21} & 0 & \dots & d_{2n} \\ . & . & . & . \\ d_{n1} & d_{n2} & \dots & 0 \end{bmatrix}. \tag{4}$$

The algorithm for the central agglomeration procedure is as follows (Nowak 1990):

1. each object O_i $(i = 1,2,...,n)$ is treated as a one-element group,
2. a minimum value is searched for in the distance matrix:

$$d_{pq} = \min_{i,j} \{d_{ij}\} \ (i\ , j = 1,...,n), \tag{5}$$

where:

n – is the number of groups currently present (in the first step, n equals the number of objects).

3. O_p and O_q objects are treated as one-element groups.
4. The clusters A_p and A_q are combined into one two-element group A_r:

$$A_r = A_p \cup A_q$$

5. The row and column numbered q are removed from the matrix D and n:=n−1, is substituted,
6. The distances d_{ir} of the newly created group A r from all other groups A_i are determined according to the method chosen. The values of d_{ir} are inserted into the matrix D in place of the p-th row (in place of the *p-th* column the elements of d_{ir}),
7. steps 2 - 5 are repeated until all objects form one group.

The general formula for transforming the distance matrix, when combining groups A_p and A_q into a new group A_r for hierarchical agglomerative methods operating according to the principle of the central agglomerative procedure has the following form (Nowak, 1990):

$$d_{ir} = a_p d_{ip} + a_q d_{iq} + b d_{pq} + c\left|d_{ip} - d_{iq}\right| \tag{6}$$

where:

d_{ir} – distance between groups A_i and A_r,
d_{ip} – distance between groups A_i and A_p,
d_{iq} – distance between groups A_i and A_q,

d_{pq} – distance between groups A_p and A_q,
ap, aq, b, c – transformation parameters specific to different grouping methods,
N_i, N_p, N_q, N_r – number of group elements A_i, A_p, A_q, A_r.

Ward's method consists in combining such clusters of A_p and A_q that, as a whole, provide the minimum of the sum of squares of the distances from the centre of gravity of the new cluster they form. The transformation of the elements of the distance matrix is performed as follows (Nowak, 1990):

$$d_{ir} = \frac{N_i + N_p}{N_i + N_r} d_{ip} + \frac{N_i + N_q}{N_i + N_r} d_{iq} - \frac{N_i}{N_i + N_r} d_{pq} \tag{7}$$

An important step in the clustering process is to determine the number of classes. One way to do this is to analyse an agglomeration flow chart. This graph shows the distances between clusters when they were combined. The best cut-off point is a clear flattening (longer vertical line), indicating distant clusters.

In the next stage of the object grouping process, the obtained classification results are verified. An interesting proposal for comparing classification results was proposed by Pociecha, Podolec, Sokołowski and Zając (1988). In this method, an assignment consistency matrix is introduced:

$$P = P_A + P_B \tag{8}$$

where:
P_A, P_B – assignment matrices in classifications A and B.

In the assignment matrix P_A, an element (i, j) is equal to 1 if objects numbered i and j are in the same subset, and 0 when they are in different subsets.
For the second division, an assignment matrix P_B.

The matrix P is a square matrix of dimension (n x n) in which the elements 0, 1, 2, denote respectively that the pair of objects in the two divisions being compared do not form a common subgroup, have been differently or equally assigned.

If classification A yields k1 subsets and classification B yields k2 subsets, then the measure of compatibility between the two classifications (W_Z) is given by the formula (Pociecha et.al., 1988):

$$W_Z = \frac{2(z_2 - n)}{\sum_{i=1}^{k_1}\left(n_i^2 - n_i\right) + \sum_{j=1}^{k_2}\left(n_j^2 - n_j\right)}, \tag{9}$$

where:
z_2 – the number of twos in the P matrix,
n_i – abundance of the i-th subgroup in classification A,
n_j – abundance j of this subgroup in the B classification,
n – number of objects.

W_Z – it is a measure that is normalised in the interval [0, 1]. The concordance between two classifications is better the higher the value of the measure. With identical classifications, W_Z = 1, while W_Z = 0, if one classification includes n one-element

subgroups and the other classification is a single group containing all elements of a set of objects.

4. AN ANALYSIS OF RESEARCH RESULTS

The following variables were taken into account in the research on SDG7 in the European Union countries:
X1 – Primary energy consumption [sdg_07_10],
X2 – Final energy consumption [sdg_07_11],
X3 – Final energy consumption in households per capita [sdg_07_20],
X4 – Energy productivity [sdg_07_30],
X5 – Share of renewable energy in gross final energy consumption by sector [sdg_07_40],
X6 – Energy import dependency by products [sdg_07_50],
X7 – Population unable to keep home adequately warm by poverty status [sdg_07_60].

Variables X4 and X5 are stimulants, the other variables are destimulants. The values of variables X1-X7 for 2013 and 2022 were downloaded from the Eurostat website (https://ec.europa.eu/eurostat/data/database). Calculations were performed using Excel, Python and Statistica 13.

The variables defining the 7th Sustainable Development Goal in 2022 were subjected to statistical verification. After calculating the coefficients of variation, it was found that values higher than 0.10 were obtained for all variables.
The inverse correlation matrix method of Malina and Zelias (1998) was used to assess the correlation of the variables. Only variable X1- Primary energy consumption showed too high a correlation, which was removed from the initial set of variables. The diagnostic variables thus remained variables X2–X7. The same set of diagnostic variables was adopted for 2013.
In the next stage of the research, using the normalised values of the variables, Ward's clustering method was applied.

The results of the grouping of EU countries in terms of the level of achievement of Sustainable Development Goal 7 in 2013 are presented in Figure 1.

Analysing the dendrogram presented in Figure 1, the EU countries were divided into 5 groups similar in terms of the implementation of Sustainable Development Goal 7 in 2013. It also seems interesting to indicate the characteristics of the groups formed. To this end, Table 1 lists the countries included in each group and the arithmetic averages of the baseline variables for the countries included in the group. The most favourable values of the output variables are indicated in bold font.

It should be noted that group I, comprising the 3 countries Belgium, Luxembourg and Ireland, has the most favourable situation in terms of variable X4 – Energy productivity. In contrast, Germany, France, Spain and Italy included in group II do not stand out in terms of the variables defining the 7th Sustainable Development Goal. The most numerous group III containing 10 countries (Czech Republic, Netherlands, Poland, Estonia, Romania, Croatia, Slovenia, Hungary, Slovakia, Latvia) had the lowest value of variable X6 – Energy import dependency by products. Countries included in group IV (Denmark, Austria, Finland, Sweden) had the most favourable values of two variables: X5 – Share of renewable energy in gross final energy consumption by sector and X7 – Population unable to keep home adequately warm by poverty status. In contrast, countries forming group V (Bulgaria, Greece, Portugal, Lithuania, Cyprus, Malta) were characterised by the lowest

values of the variables: X2 – Final energy consumption, X3 – Final energy consumption in households per capita.

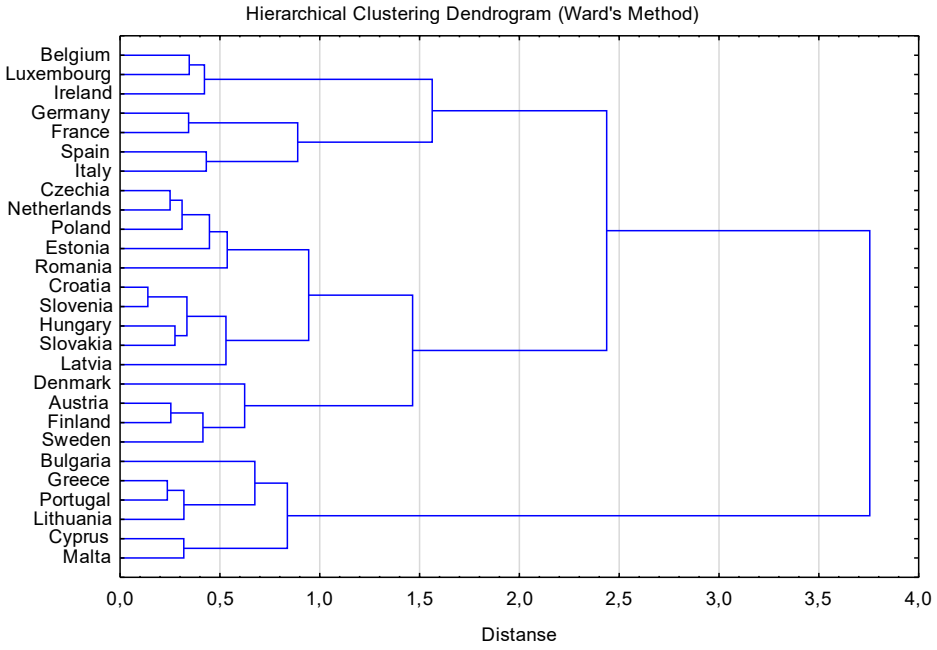

Figure 1. Grouping of EU countries by level of achievement of Sustainable Development Goal 7 using the Ward method in 2013

Source: own elaboration.

Table 1. Average values of output variables across EU country groups in 2013

Groups	X2	X3	X4	X5	X6	X7
I: Belgium, Luxembourg, Ireland	17.23	791.67	**9.69**	6.23	88.81	5.80
II: Germany, France, Spain, Italy	144.15	590.50	8.33	14.86	64.28	9.68
III: Czech Republic, Netherlands, Poland, Estonia, Romania, Croatia, Slovenia, Hungary, Slovakia, Latvia	20.73	597.40	4.45	19.39	**36.97**	9.40
IV: Denmark, Austria, Finland, Sweden	24.68	841.50	8.83	**36.66**	39.01	**2.15**
V: Bulgaria, Greece, Portugal, Lithuania, Cyprus, Malta	**7.80**	**322.00**	5.32	15.80	74.86	30.98

Source: own elaboration.

In order to answer the question: has there been a change in the composition of the different groups of EU countries in terms of the implementation of Sustainable Development Goal 7, the Ward method was also applied to the 2022 data. The results are presented in Figure 2 and Table 2.

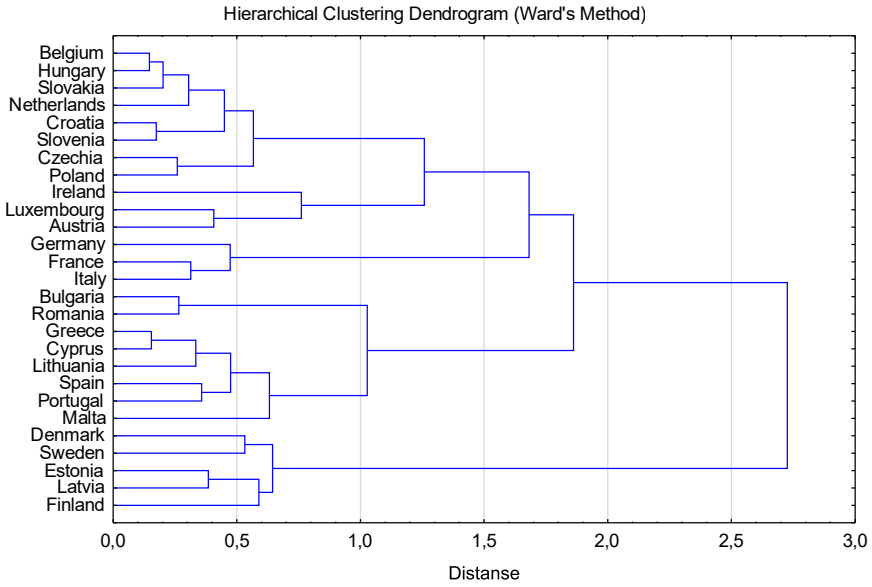

Figure 2. Grouping of EU countries in terms of their level of achievement of Sustainable Development Goal 7 using the Ward method in 2022

Source: own elaboration.

Table 2. Average values of output variables across EU country groups in 2022

Groups	X2	X3	X4	X5	X6	X7
I: Belgium, Hungary, Slovakia, Netherlands, Croatia, Slovenia, Czech Republic, Poland, Ireland, Luxembourg, Austria	23.90	590.91	9.28	18.47	68.24	5.10
II: Germany, France, Italy	151.13	580.33	**10.67**	20.02	66.63	8.70
III: Bulgaria, Romania, Greece, Cyprus, Lithuania, Spain, Portugal, Malta	19.48	**362.88**	6.70	23.14	69.78	16.91
IV: Denmark, Sweden, Estonia, Latvia, Finland	**14.90**	735.80	8.80	**47.46**	**31.10**	**4.06**

Source: own elaboration.

For the 2022 data, 4 groups of EU countries with similar levels of achievement of the 7th Sustainable Development Goal were created. The largest group I, containing 11 countries, did not stand out in terms of the variables defining Sustainable Development Goal 7.

The special feature of group II (Germany, France, Italy) was the highest level of variable X4 – Energy productivity. Countries classified in group III: Bulgaria, Romania, Greece, Cyprus, Lithuania, Spain, Portugal, Malta, were characterised by the most favourable situation in terms of variable X3 – Final energy consumption in households per capita. Group IV countries (Denmark, Sweden, Estonia, Latvia, Finland) were the leaders in the implementation of Sustainable Development Goal 7, dominating in terms of as many as four variables, i.e. X2 – Final energy consumption, X5 – Share of renewable energy in

gross final energy consumption by sector, X6 – Energy import dependency by products, X7 – Population unable to keep home adequately warm by poverty status.

The conformity of the grouping results of EU countries in terms of the implementation of Sustainable Development Goal 7 in 2013 and 2022 was assessed using the Pociecha, Podolec, Sokolowski and Zając (1988) measure (formula 9). The calculated value of 0.556 determines a moderate conformity of the grouping results, which may indicate that gradual changes in the composition of the different country groups are taking place. It can be noted that in 2022 compared to 2013, the position of the leaders in achieving Sustainable Development Goal 7 (Denmark, Sweden, Estonia, Latvia, Finland) has strengthened. Quite a number of EU countries including Belgium, Hungary, Slovakia, Netherlands, Croatia, Slovenia, Czech Republic, Poland, Ireland, Luxembourg, Austria, have not yet achieved satisfactory results in ensuring access to affordable, reliable, sustainable and modern energy for all. A lot of work still needs to be done by Germany, France, Italy, achieving unfavourable values in relation to other EU countries, especially for the variables: X2 – Final energy consumption and X3 – Final energy consumption in households per capita.

5. DISCUSSION

In order to achieve the goals set out in Agenda 2030, including SDG 7, there is a great need to transform the economies of the EU27. The European Union is very diverse and complex in terms of the energy efficiency of each Member State, but very similar in terms of the challenges: supply shortage, climate change, rising prices and import dependency. By replicating the best examples taken from the leading countries in this field and avoiding the worst practices, the governance of the entire energy system can be improved (Momete, 2023).

The literature highlights the importance of sustainable energy development and how to measure it in individual EU countries or the EU as a whole (Neelawela et al, 2019; Herrero et al, 2020; Elavarasan et al, 2022). However, studies conducted so far show that there is a lack of consistent methods used to group countries similar in terms of their level of SDG7 achievement. There is still a need to identify new approaches to analyse this phenomenon. It should be noted that attempts to assess sustainable development in EU countries using Ward's method were already made by the authors in 2016 and allowed to draw many interesting conclusions (Stec, Grzebyk, 2017).

Summarising the results of the research conducted in this article, it was observed that the level of implementation of Sustainable Development Goal 7 in the European Union was not homogeneous. In terms of individual countries, there was evidence of a higher level characteristic for the northern Member States and a lower level for the southern European countries. Poland is part of the group of central European countries in which none of the analysed variables determining the level of implementation of Sustainable Development Goal 7 was leading. The results are similar to those achieved by other authors despite the use of different research methods.

An example is the study by Firoiu et. al. (2021). The authors focused on the development of clusters (A to D), i.e. a breakdown of countries achieving similar levels of SDG 7 target achievement in 2015 and 2019. In 2015, the best-performing countries were grouped in cluster C and included Denmark, Finland, Romania and Sweden. The worst-performing countries were grouped into cluster D and included Cyprus, Ireland, Lithuania, Luxembourg and Malta. Similar results were achieved in 2019. Countries grouped in cluster C were again found to be the most advanced in meeting SDG target 7, while the

worst performers were countries grouped in cluster D. Through this research, it was possible to distinguish a group of the best countries, as well as those that require increased attention and support. An important element of the research was that the group of best-performing countries has grown, demonstrating a real concern and commitment to SDG Goal 7.

Other findings were carried out by Dmytrów, et.al. (2022). Their aim was to compare selected European countries in terms of the degree of SDG7 implementation using the COPRAS method between 2005 and 2020. The highest ranked countries were Norway, Denmark, Estonia, Croatia, Latvia, Sweden and the UK. In contrast, the least committed countries in the implementation of SDG7 were: Belgium, Bulgaria, Cyprus, Lithuania and Finland.

The main conclusion of the research presented was that the achievements of the most developed countries should be an incentive for those at a lower level of development, and that changes in the positions of these countries should reflect the development pathway for achieving SDG7.

6. CONCLUSIONS

In the perspective of the changes taking place in the modern world, humanity cannot afford to ignore the issue of the environment and social exclusion, therefore sustainable development subject, including the implementation of SDG 7, should not only remain in the consciousness of individual societies, but also be translated into the actions of decision-makers on a national and international scale.

The current turbulent times, with the world still recovering from the COVID-19 pandemic, the invasion of Ukraine underway, energy prices volatile and inflationary pressures threatening political stability, mean that national governments need to address the energy transition.

Each country needs to find the most appropriate combination of measures for itself, which should range from increasing energy intensity, implementing the right mix of renewables, increasing investment in renewables or introducing new regulations (Momete, 2023).

The results of the study show that there was a systematic improvement in the degree of achievement of the EU's SDG 7 target in the years under review (2013 and 2022). The gap between the European Union countries narrowed markedly, although southern and eastern European countries were still furthest away from the 2030 target. They have a lot of backlog in the implementation of this target. It is also noted on the basis of research that the northern European countries are doing best in the implementation of SDG7, and their situation is still improving. However, it should be highlighted that the final ranking of countries was fundamentally influenced not only by the initial choice of diagnostic variables, but also by the research method used.

The grouping of EU Member States on the basis of the criteria identified in this study may contribute to finding targeted solutions for each group of countries, or may lead to the development of more efficient resource allocation models and better alignment of public policies to support the achievement of the desired level of SDG7 implementation.

The presented results of the analysis can provide policy makers, researchers and other stakeholders with useful knowledge, showing the existing development gaps between countries or groups of countries. They also provide constructive information that may

prove useful in the development of future strategic plans related not only to the implementation of SDG7, but also to the implementation of other Agenda 2030 goals.

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