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DIVERSIFICATION OF THE LEVEL OF SUSTAINABLE DEVELOPMENT IN EU MEMBER STATES WITH THE USE OF TAXONOMIC METHODS

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ABSTRACT: The aim of this article is to define the degree of sustainable development in EU member states with the use of various taxonomic methods. The first part of the article addresses the issues related to the definition of sustainable development and the methods used to assess the level of this phenomenon. The second part is dedicated to the assessment of the level of sustainable development in EU member states on the basis of statistical data from the year 2010 and 2015. The possible use of multidimensional comparative analysis was pointed out to define the degree of sustainable development. Linear classification of EU member states in terms of sustainable development level was carried out on the basis of standard and non-standard methods. Moreover convergence of the classifications was examined. Ward's method and the PAM method were used to group EU member states in terms of similar sustainable development level.

KEY WORDS: sustainable development, sustainable development indicator, linear classification, object grouping

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Introduction

Together with the growing criticism of Gross Domestic Product being a measuring instrument of social prosperity, numerous indicators and aggregate data have been developed to assess this phenomenon. As time went by, they were subject to "greening", which consisted in the correction of economic results and cost adjustment resulting from the depreciation of natural capital, referring to the idea of sustainable development – a concept much broader than conventional economic development. Due to the multi-faceted nature of sustainable development, the construction of measuring instruments is substantial when it comes to the assessment of its degree as they function as both information and diagnostic barometers, thus being fundamental to analyses and comparisons on local, regional, national and international levels.

The aim of this article is to assess the degree of sustainable development in EU member states in the years 2010 and 2015 on the basis of taxonomic indexing methods. In order to quantify the degree of sustainable development, multidimensional statistical analysis based on synthetic development indicators were used. Despite numerous analyses, measuring the level of sustainable development in individual regions still remains an issue, which has not been fully solved. The author claims this issue concerns the selection of diagnostic variables (diverse formal and substantive criteria), methods used to measure the phenomenon, as well as methods used to group objects under analysis. When using different taxonomic methods, researchers oftentimes marginalize the necessity of compliance and grouping classification or neglect to verify if the object grouping was carried out correctly. The first part of the article presents theoretical aspects of the level of sustainable development as well as synthetically describes chosen measuring methods of this phenomenon. By applying standard and non-standard methods, linear classification of analyzed objects was carried out. Furthermore, the classification of analyzed objects was performed with use of Ward's method and PAM method. The selection of partial variables was done on the basis of substantial, statistical and formal criteria. 28 EU member states were subject to this analysis.

Sustainable development indicators

Despite the term "sustainable development" being widely popular both in scientific publications and different legal documents, the definition and thus was of measuring remain an object of heated discussion among researchers. W. Florczak (2011) lists out the following common characteristics found in numerous definitions of sustainable development: the rejection of zero growth concept to bring together ecological and socio-economic problems; interaction between the economic, ecological, demographic and social components of development; emphasis on the necessity for the whole society to be engaged in the implementation of the principles of sustainable development; necessity of analysis of the consequences of decisions made on future generations; the principle of distributive justice; emphasis on the role of non-material aspects of life.

Taking these issues into consideration as well as the multi-aspect nature of the level of sustainable development, quantification poses a significant problem. With regards to this matter, research conducted at the end of the 1990s deserves special consideration, among others by J. Śleszyński (among others *Agregatowe wskaźniki trwałego rozwoju*, 1998), T. Borys (among others *Wskaźniki ekorozwoju*, 1999), B. Fiedor (among others *System wskaźników i indeksów ekorozwoju*, 1996), which significantly contributed to the popularization of research regarding the quantification of sustainable development or eco-development. Among more current research on measuring sustainable development on the basis of taxonomic analysis, the analyses of E. Roszkowska and R. Karwowska are worth mentioning. The authors performed an analysis and assessment of how the concept of sustainable development of Polish voivodships in 2010 is being accomplished, on the basis of synthetic measure of the level of development (the average of normalized values of simple features) (see: Roszkowska, Karwowska, 2014). As part of a research M. Reiff, K. Surmanová, A.P. Balcerzak and M.B. Pietrzak based on Hellwig's method and Ward's method assessed the efficiency diversification of agricultural sectors in the EU (see: M. Reiff, K. Surmanová, A.P. Balcerzak, M.B. Pietrzak, 2016). As a result of attempts to measure this phenomenon, very diversified measures have been created, applicable in domestic and international comparative analyzes. They enable the monitoring and assessment of the progress of implementation of sustainable development goals set by individual societies.

One of these measures is the so-called „Ecological footprint", which is used as a measure of people's demand for broadly defined natural capital. According to E. Lazarus and others „ecological footprint" determines how many biologically productive land and sea areas are necessary to provide resources for consumption and to absorb generated waste, based on existing technological solutions combined with specific practices in resource management (Lazarus et al., 2014). Another measure used to quantify the level of sustainable development is the *Environmental Performance Index* (EPI). In 2016, this measure was constructed on the basis of over 20 indicators aggregated in 9 thematic areas: impact on health, air quality, drinking water and sanitation, water resources, agriculture, afforestation rate, fishing grounds, biodiversity of species and habitats, climate and energy. The first three groups of indicators are distinguished within the framework of the strategic objective of health protection, while the remaining ones concern the protection of ecosystems (HSU, 2016). In the context of measurement of sustainable development – especially in the social sphere – the Human Development Index (HDI) is often used (for instance under the United Nations Development Program), taking into account the GDP per capita, as well as life expectancy at the time of birth and the level of education (UNDP, 2015a). The derivative of the HDI index is a relatively new (applied for the first time in 2010) *Multidimensional Poverty Index* (MPI), which replaced the HPI (*Human Poverty Index*) index used since 1997. It includes 10 elements aggregated in 3 dimensions (UNDP, 2015b): I. Education (1. no household member studied for at least 6 years; 2. school-age child does not attend school); II. Health (1. at least one member of the household is undernourished 2. child mortality); III. Living conditions (1. no access to electricity, 2. no access to clean drinking water, 3. no access to sanitary facilities, 4. use of „dirty cooking fuel", 5. mess at home, 6. having at the most one piece of property related to: access to information (radio, television, telephone), mobility or subsistence (fridge, arable land, livestock)). One of the first measures of economic well-being taking into account the environmental aspect in a greater extent was the EAW index (*Index of the Economic Aspects of Welfare*), used by X. Zolotas in 1981. Its construction is based on the current flow of goods and services. It includes expenses related to public buildings, value of work in households, spending on durable consumer goods, advertising, value of free time, value of public sector services, adjusted by expenses related to health and education, costs of environmental pollution and depletion of natural resources (Redclif, 2005). *The Index for Sustainable Economic Welfare* (ISEW) was developed in 1989 by H. Daly and J. Cobb. The first step in the construction of this measure is to adjust the personal expenditure of a given population by indexing the income spread. Next, the value obtained is modified by adding or subtracting monetary values from a predetermined set of factors (of social, economic and environmental nature), depending on whether a given factor has a positive or negative impact on prosperity (Lawn, 2003; Gasparatos et al., 2008).

Classification and grouping of EU member states in terms of sustainable development level

The analysis of spatial diversity of the EU member states in terms of the level of sustainable development requires comparison of many research objects described with the help of a large set of variables, therefore it is difficult to express the level of this phenomenon by one measurable feature. In order to quantify the degree of sustainable development, multidimensional statistical analysis based on synthetic development indicators were used (which replace the description of objects using a series of variables with one aggregated quantity).

In the source literature, it is difficult to find a universal list of indicators used to quantify the level of sustainable development of individual areas, but three basic dimensions can be considered without major reservations in the analysis of the level of this phenomenon (Borys, 2011; GUS, 2011): economic (including socio-economic infrastructure, employment structure), social (including health, culture) and environmental (including air quality). Therefore, taking into account the criterion of availability and completeness of data, 42 indicators have been proposed, divided into three dimensions:

- environmental: OS1 – electricity consumption by households (1000 tons of oil equivalent); OS2 – energy consumption in transport in relation to GDP; OS3 – municipal waste recycling rate; OS4 – production of waste by economic entities (t/km^2); OS5 – pollution, soot or other environmental problems (percentage of population exposed); OS6 – chemical and medical waste (t/km^2); OS7 – greenhouse gas emissions; OS8 – emission of sulfur oxides by the source sector (t/km^2); OS9 – ammonia emission by the source sector (t/km^2); OS10 – emission of non-methane volatile organic compounds (t/km^2); OS11 – energy generated from renewable sources (in %);
- social: S1 – number of entities involved in the production of animated films, video and tv programs, sound recording and publishing activity per 1 person; S2 – population density; S3 – number of people killed in road accidents per 1000 people; S4 – percentage of people with higher education; S5 – income replacement indicator; S6 – median income (PPS); S7 – inability to meet unexpected financial expenses (percentage of population); S8 – inequality of income distribution; S9 – percentage of people experiencing deep material deprivation; S10 – crime, violence or vandalism in the area (percentage of the population); S11 – people leaving education and schooling prematurely (in % of the total population); S12 – people living in households with very low work intensity (in% of the total population); S13 – subjectively perceived health condition (as very good – in %); S14 – neonatal mortality rate; S15 – share of children under the age of 3 in institutional care; S16 – the impact of social transfers (excluding pensions) on reducing poverty; S17 – fertility rate; S18 – indicator of severe housing deprivation; S18 – participation rate in education and training (last 4 weeks); S19 – differentiation of salary based on sex; S20

– percentage of people at risk of poverty or social exclusion; S21 – life expectancy.

- economic: G1 – GDP per capita (in EUR); G2 – expenditure on research and development (% of GDP); G3 – gross debt of the general and local government sector (% GDP); G4 – unemployment rate; G5 – eco-innovation index (EU=100); G6 – density of motorways[1]; G7 – total expenditure of the public finance sector (% of GDP); G8 – energy intensity of the economy; G9 – energy efficiency of the economy (in euro per kilogram of oil equivalent); G10 – economic activity indicator.

Due to the fact that many authors question the validity of the weighing procedures for variables referring to spatial data, for the purposes of these analyzes, the assignment of diagnostic weight factors to variables was omitted. The fact that for instance variables that were not selected would have zero weight in advance, would argue for such a solution (Balicki, 2009; Młodak, 2006). From the set of potential variables, the features for which the value of the coefficient of variation (in both analyzed periods) was smaller than the arbitrarily determined, critical threshold value of this coefficient of 10% were eliminated. In addition, it is commonly accepted that two highly correlated variables convey similar information, so it is recommended to eliminate one of them. Therefore, the so-called inverted correlation matrix method is used to assess information value. This method consists in determining the matrix inverse to the matrix of correlation coefficients between variables. If there is such a necessity, the variable for which the corresponding diagonal element of the inverse correlation matrix was characterized by the highest value exceeding the arbitrarily set threshold value (usually r*=10) is eliminated. The inverse correlation matrix is then recalculated and checked if the diagonal values do not exceed the set threshold. The action is continued until all diagonal values, which do not exceed the established threshold value have been reached (Młodak, 2006; Panek, Zwierzchowski, 2013). For the purposes of the article, for each subject subgroup of variables, the inverse correlation matrix was calculated. If necessary, the variable corresponding to the diagonal element of the matrix inverse to the correlation matrix with the highest value was eliminated, simultaneously exceeding the arbitrarily set threshold value.

The above set of diagnostic features was reduced due to the low degree of differentiation, eliminating variables related to life expectancy and professional activity rate. However, due to the low discriminatory capacity (in both periods analyzed), the variable related to the number of people at risk of pov-

[1] Due to the lack of access to more current data, the indicators referring to the density of motorways in Denmark, Belgium, Cyprus and Malta refer to the year 2012. This data comes from: *Road Statistics Yearbook 2016*.

erty was eliminated. The variables included in the set of destimulant are: OS1, OS2, OS4-OS10, S3, S7-S12, S14, S18, S19, G3, G4, G8. The other variables are stimulant. Due to the requirement to ensure the comparability of final diagnostic variables in taxonomic analyzes, a standardization process was carried out using classical standardization.

In order to organize the EU countries due to the level of sustainable development, four methods of linear ordering were used (non-standard (average rank method and standardized sum method) and standard (distance method and TOPSIS method) (wider: Balicki, 2009; Dziechciarz, 2002; Młodak, 2006; Panek, Zwierzchowski, 2013; Hwang, Yoon, 1981). The calculated synthetic development measures reflect the position of EU countries in particular years, in relation to other areas. In the case of the TOPSIS method, standardized sum methods and average rank methods, the higher value of the synthetic development measure means a higher level of the studied phenomenon, while in the case of the distance method the interpretation is reversed. It is worth noting that for all the methods used, the highest measures were recorded in Sweden, Denmark and Luxembourg.

Based on the values of synthetic development measures, rankings of EU countries were created focusing on the level of sustainable development. For all the methods used, Bulgaria finished last both in 2010 and in 2015. Also Latvia didn't get very high in the ranking based on the data from 2010 (three times came 27th and once 26th in the case of the middle-ranking method) and Romania (which finished on the 27th place (average rank method) twice 26th (sum method and distance method) and 25th place in the ranking based on the TOPSIS method). For the 2015 data, Greece was identified most frequently (three times) as next to last, and slightly better results were observed in the case of Malta. Such low ranks of these countries come from low or very low values of the included partial variables.

Poland in the created rankings came 17th for the 2010 data (for the TOPSIS method), 18th (for the standardized sum method and the distance method) and 23rd for the middle rank method. In turn, for 2015 data, Poland ranked 15th in the rankings created by three methods: distance method, TOPSIS method, sum method, and only 25th in the ranking created on the basis of the average rank method. These disproportions are related to high values in a given period of a synthetic measure taking into account the dispersion of the analyzed variables (distance method, TOPSIS method, sum method) and at the same time a lower value of the measure that does not take into account the variation of features, which is the rank arithmetic average (rank method). Analyzing the results of the linear ordering of EU countries in terms of the level of sustainable development, it is easy to notice that in individual years there have sometimes been significant shifts in the rankings

Table 1. A synthetic measure of the level of sustainable development of EU member states

	The value of synthetic measure								Ranking							
	Non-standard methods				Standard methods				Non-standard methods				Standard methods			
	I		II		III		IV		I	II	III	IV	I	II	III	IV
	10′	15′	10′	15′	10′	15′	10′	15′	10′	15′	10′	15′	10′	15′	10′	15′
AT	0,44	0,55	16,17	16,39	0,34	0,24	0,61	0,61	5	5	5	4	5	4	5	5
BE	0,34	0,45	13,95	14,17	0,50	0,41	0,55	0,55	11	11	11	11	10	11	13	12
BG	0,00	0,00	8,56	7,73	1,00	1,00	0,45	0,41	28	28	28	28	28	28	28	28
HR	0,20	0,29	12,05	12,20	0,74	0,64	0,51	0,51	22	21	18	18	23	24	23	23
CY	0,27	0,31	12,88	12,22	0,61	0,59	0,55	0,52	14	19	14	16	17	22	14	19
CZ	0,29	0,39	12,73	12,95	0,54	0,44	0,56	0,56	13	12	16	14	13	13	11	11
DK	0,53	0,67	18,10	18,51	0,22	0,16	0,65	0,65	2	2	2	2	2	2	2	2
EE	0,22	0,33	11,66	12,71	0,67	0,54	0,53	0,54	20	18	21	15	20	18	19	16
FI	0,46	0,55	17,02	16,39	0,31	0,29	0,63	0,61	4	4	4	5	4	7	4	6
FR	0,37	0,49	14,68	14,76	0,42	0,32	0,58	0,58	9	9	9	9	9	10	8	10
GR	0,19	0,17	10,63	9,22	0,74	0,76	0,50	0,46	24	27	24	27	22	26	24	27
ES	0,27	0,34	13,02	13,22	0,56	0,51	0,54	0,53	15	16	13	13	14	16	15	17
NL	0,40	0,50	15,61	14,90	0,42	0,30	0,58	0,58	6	6	6	7	8	8	9	9
IE	0,40	0,50	15,49	15,20	0,53	0,28	0,57	0,61	7	7	7	6	12	6	10	4
LT	0,19	0,29	11,71	11,54	0,74	0,58	0,52	0,52	23	22	19	22	24	21	21	18
LU	0,49	0,60	17,32	16,51	0,29	0,22	0,63	0,62	3	3	3	3	3	3	3	3
LV	0,09	0,27	10,07	11,54	0,88	0,59	0,48	0,52	27	23	26	21	27	23	27	20
MT	0,11	0,18	10,17	11,29	0,85	0,78	0,48	0,47	25	26	25	24	25	27	26	26
DE	0,31	0,39	13,56	13,39	0,51	0,43	0,55	0,54	12	13	12	12	11	12	12	13
PL	0,23	0,34	10,83	11,29	0,65	0,50	0,53	0,54	18	15	23	25	18	15	17	15
PT	0,26	0,33	12,78	12,22	0,60	0,51	0,53	0,52	16	17	15	17	16	17	16	21
RO	0,10	0,19	9,68	9,85	0,85	0,74	0,49	0,49	26	25	27	26	26	25	25	25
SK	0,23	0,36	11,59	12,20	0,67	0,50	0,53	0,54	19	14	22	19	19	14	18	14
SL	0,38	0,49	15,27	14,73	0,40	0,32	0,59	0,58	8	8	8	10	7	9	6	8
SE	0,61	0,72	19,59	19,61	0,00	0,00	0,72	0,69	1	1	1	1	1	1	1	1
HU	0,21	0,30	11,68	11,71	0,68	0,57	0,52	0,51	21	20	20	20	21	20	22	22
GB	0,35	0,45	14,22	14,78	0,39	0,27	0,58	0,59	10	10	10	8	6	5	7	7
IT	0,25	0,27	12,17	11,37	0,57	0,57	0,53	0,49	17	24	17	23	15	19	20	24

Legend: I – The method of standardized sums, II – Average rank method, III – Distance method, IV – TOPSIS method.

AT – Austria, BE – Belgium, BG – Bulgaria, HR – Croatia, CY – Cyprus, CZ – Czech Republic, DK – Denmark, EE – Estonia, FI – Finland, FR – France, GR – Greece, ES – Spain, IE – Ireland, LT – Lithuania, LU – Luxemburg, LV – Latvia, MT – Malta, NL – Netherlands, DE – Germany, PL – Poland, PT – Portugal, RO – Romania, SK – Slovakia, SL – Slovenia, SE – Sweden, HU – Hungary, GB – Great Britain, IT – Italy.

Source: author's own work based on data from Eurostat, http://ec.europa.eu/eurostat; Road Statistics Yearbook 2016.

created under the given method. In the analyzed period, the greatest advancement was recorded in the case of Italy (depending on the method, by at least 4 places) and Cyprus (for the three methods used it was a advancement by 5 places). The largest drop in the rankings created was identified in the case of Latvia and Estonia (depending on the adopted method, it was a decrease in the ranking between 4th and 7th places in the case of Latvia and between 2nd and 6th place in the case of Estonia). On the basis of synthetic values of development measures and created rankings, it can be stated without any reservations that in the spatial differentiation of the level of sustainable development of EU countries, there is no clear division into the western part and the eastern part of these associated countries. On the other hand, Nordic countries – Sweden, Denmark and Finland topped the ranking. In order to evaluate the convergence of the classification results obtained by four taxonomic methods, the values of Spearman's rank correlation coefficients were calculated between them. In the years analyzed, these coefficients are very high and in each case exceed the value of 0,92. In order to supplement the analysis, Kendall's τ correlation coefficients were calculated (Spearman's rank correlation coefficient does not take into account the fact that the distances between neighboring values are unknown (and not equal)). The analysis of Kendall's τ correlation coefficients confirmed the high consistency of obtained classification.

Table 2. Conformity of the results of the classification of EU countries based on the level of sustainable development

	Distance method (2010/2015)		TOPSIS method (2010/2015)		The method of standardized sums (2010/2015)		Average rank method (2010/2015)	
	I	II	I	II	I	II	I	II
Distance method	1,000*	1,000*						
TOPSIS method	0,979*/ 0,973*	0,899*/ 0,894*	1,000*	1,000*				
The method of standardized sums	0,981*/ 0,975*	0,921*/ 0,899*	0,984*/ 0,976*	0,915*/ 0,899*	1,000*	1,000*		
Average rank method	0,955*/ 0,928*	0,831*/ 0,810*	0,953*/ 0,933*	0,825*/ 0,820*	0,977*/ 0,949*	0,899*/ 0,857*	1,000*	1,000*

Legend: I – Spearman's rank correlation coefficient, II – Kendall's τ correlation coefficient.
* statistically significant at the significance level p <0,05.

Source: author's own work.

Due to the high compliance of the classification results, further analysis focuses on the results obtained with the TOPSIS method. On the basis of the analysis of the value of measures for sustainable development, it can be concluded that there is moderate variation in the level of this phenomenon in the EU (measured at the national level). The average value of the constructed measure in 2010 was 0,5543, while in 2015 it was 0,5484. The coefficient of variation was 0,1050 and 0,1101 in 2010 and 2015 respectively. It is worth noting that in both analyzed years this measure was characterized by right-sided asymmetry (in 2010 the asymmetry index was 0,7848, while in 2015 0,1639), which means that values not exceeding the arithmetic average predominated. In 2010, for three-quarters of EU countries, the synthetic measure of the level of sustainable development did not exceed the value of 0,5196, with the maximum value of 0,7176 and the minimum 0,4501, while in 2015 in 75% of the analyzed countries the value of 0,5851 with the maximum value of 0,6932 and a minimum of 0,4109.

In order to deepen the analysis, the EU countries were classified according to two methods based on taxonomic similarity – the Ward's method (as a way to measure the distance between objects a square of Euclidean distance was used (to assign more weight to objects further away from the others)) and PAM method (Partitioning Around Medoids). The Ward's method aims to minimize the square deviations from the mean within clusters. One of the basic problems that appear in the Ward's method is to determine the so-called critical distance size at which the arms of the dendrogram[2] are cut off and thus the clusters of the objects are determined. In order to limit subjectivity one of the assisting techniques based on the following formula was used (Panek, Zwierzchowski, 2013):

$$d_{i+1}^{*} > \overline{d} + ks_{d} \ ,$$

where: d_{i+1}^{*} – critical value of the distance corresponding to *i+1* branch length; $\overline{d}$, s_d – arithmetic mean and standard deviation of tree branch length; k – parameter whose optimal value is estimated at 1,25.

For the data from 2010, the critical value of the distance at which the dendrogram's arms were cut was 214,08, while for the data from 2015, 210,43.

The less frequently used classification method is the relatively new PAM division method, which is a modified version of the *k*-means method. The algorithm[3] consists in finding *k* representative objects that are centrally located in clusters (so-called medoids). The cluster representative is an

2 The effects of using Ward's method are often presented in the form of a tree diagram – a dendrogram.

3 The simplified algorithm is described on the basis of UNESCO, 2008 pp. 321-323.

object in which the average dissimilarity (distance to the representative) of all objects in the cluster is minimal. The selection of *k* medoids is done in two stages. The first stage is based on a preliminary division through another selection of representative objects, until the verification of *k* objects. The first object is the one for which the sum of dissimilarities to all other objects is as small as possible. Then, in each step, an object is chosen that reduces the function of the goal (sum of dissimilarity) as much as possible. The second phase is an attempt to improve the set of representative objects. This is done by including all pairs of objects (*i, h*) for which the object has been selected for the set of representatives, and *h* does not belong to the set of representatives, checking whether, after swapping *i* and *h*, the target function decreases.

Based on the criterion adopted to determine the critical distance size at which the arms of the dendrogram are cut off, in the case of the Ward's method, three groups of countries were created (in both periods analyzed). In order to ensure the comparability of classification results, in the case of the PAM method, the same number of groups was arbitrarily assumed. Grouping results are presented in descending order according to arithmetic means of synthetic measures (obtained with the TOPSIS method) within a given cluster.

Table 3. Classification of EU countries by the level of sustainable development

Gr.	2010	2015
	Ward's Method	
I	SL, PT, IT, ES, GR, CY, FI, SE, AT, DK, GB, IE, FR, DE, BE, LU, NL	IE, GB, FR, DE, SL, FI, AT, SE, DK, LU, BE, NL
II	BG, CZ, EE, HR, LV, LT, HU, PL, RO, SK	GR, ES, IT, CY, PT, BG, CZ, EE, HR, LV, LT, HU, PL, RO, SK
III	MT	MT
	PAM method	
I	BE, DK, IE, FR, LU, NL, FI, SE, GB	BE, IE, FR, LU, MT, NL, AT, FI, SE, GB
II	DE, GR, ES, IT, CY, MT, AT, PT	DE, DK, GR, ES, IT, CY, PT, SL
III	BG, CZ, EE, HR, LV, LT, HU, PL, RO, SL, SK	BG, CZ, EE, HR, LV, LT, HU, PL, RO, SK

Source: author's own work.

The use of different classification methods has contributed to various grouping results in the analyzed years. These inconsistencies may arise, inter alia, from a different way of calculating the distance between objects, or the distance between the clusters themselves. In the case of the Ward's method, in both analyzed years a single-element group was distinguished, which included Malta. It is clear that for the 2010 data, all countries included in the first group created on the basis of the PAM method are included in the first group formed by the Ward's method (for the data from 2015, the exception being Malta). In the case of grouping results obtained by the Ward's method, it is much easier to identify the clusters of countries that form extensive and compact spatial areas with a similar level of this phenomenon (this is mainly due to the much larger (compared to PAM results) concentration of countries only in the first two groups created). For the 2010 data, this mainly applies to countries in the first group: Portugal, Spain, France, Luxembourg, Belgium, the Netherlands, Denmark, Germany, Austria, Slovenia and Italy. For the data from 2015, this applies mainly to countries belonging to the second selected group: Estonia, Latvia, Lithuania, Poland, the Czech Republic, Slovakia, Hungary, Romania, Bulgaria and Greece. The adjusted Randa index was used to assess the conformity of the obtained classifications by PAM and Ward's methods. This index takes values from the interval [0,1], where the value of 1 means identical results of grouping of objects, while 0 when the compared orderings are independent. The value of the Randa index for the 2010 data was 0,7407, while for the data from 2015 0,7354. After classification using different methods, their correctness was verified. For this purpose, measures of homo- and heterogeneity were determined. Homogeneity meters determine the level of cluster unification. This unification increases if the objects in the group are closer together. In turn, heterogeneity meters measure the level of individuality in groups of objects. For the assessment of cluster homogeneity, a meter reflecting the average arithmetic distance of objects in the group was used:

$$hm = \frac{1}{k}\sum_{l=1}^{k}\overline{d_l}; \quad \overline{d_l} = \frac{1}{(n_l^2 - n_l)}\sum_{i=1}^{n_l}\sum_{j=1}^{n_l} d_{i,j},$$

where: n_l – number of *l-th* of a group; *k* – number of groups.

However, in order to assess the heterogeneity of clusters, a meter was calculated that reflects the arithmetic mean between groups, expressed by the formula:

$$hr = \frac{1}{k}\sum_{l=1}^{k} d_{\min}^{(l.l')}, \; d_{\min}^{(l,l')} = \min_{p}(\min_{o \notin \{p\}} d_{p,o}),$$

where: {p} – a set of objects from the *l*-th group; *p* – object belonging to the set {p}; *o* – collection of objects not belonging to the group of *l*.

The cluster correctness meter is the quotient of homogeneity and heterogeneity measures.

Table 4. Total measures of homogeneity, heterogeneity and correctness of clusters

	Summary measures					
	Homogeneity		Heterogeneity		Correctness	
	I	II	I	II	I	II
2010	7,394	35,600	5,613	58,856	1,317	0,605
2015	7,374	38,131	5,176	59,198	1,425	0,644

Legend: I – PAM method; II – Ward's method
Source: author's own work.

The results of the assessment of the effectiveness of the conducted groupings in particular years indicate that the Ward's method is more effective for the analyzed set of variables. In the case of this method, higher measures of clustering heterogeneity than homogeneity measures were observed – inversely than in the PAM method.

Conclusion

Relatively easily accessible statistics on national and international economic, social and environmental issues make the search for indicators and constructing aggregate measures of sustainable development level an important research direction since many years. Despite numerous analyzes, searching for new indicators and measures, and making analyzes in dynamic and spatial terms, it seems that the research should be continued. This is particularly important for justifying the sense of implementing sustainable development principles and monitoring the progress of the implementation of these principles in a given area. The results of this type of research can be an impulse to correct and update the actions adopted in the strategic records. The article defines synthetic measures of the level of sustainable development, using four taxonomic methods, which were used to rank EU member states with regards to the level of the analyzed phenomenon. As a result of the conducted research, groups of countries with a similar level of sustainable development were created. The analysis shows that the highest level of sustainable development can be found in Sweden, Denmark and Luxembourg. In the years taken into account, Bulgaria came last. In the analyzed period, the diversification of the level of sustainable development in the EU countries can only be assessed as moderate. It should be emphasized that despite the application of different methods of linear classification with regards to the level of sustainable development, in the years analyzed no significant differences were observed between the places of individual countries in the ranking, which indicates the consistency of classification.

The contribution of the authors

Magdalena Jaworska – 50% (concept, theoretical part, conclusions).

Mariusz Malinowski – 50% (data collection, analysis and interpretation of results).

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