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Sustainable Development and Innovations-
How They Work Together?

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Abstract:

Purpose: *The main purpose of the paper is the elaboration and verification of a comprehensive proposal for measuring the results achieved by selected global economies in the area of sustainable development and innovation.*
Approach/Methodology/Design: *To compare the results obtained by EU countries the multi-criteria taxonomy methods were used. The basis of empirical research are the indicators used by the European Commission to monitor the progress in the implementation of the Strategy for Sustainable Development – Agenda 2030 and the indicators used to assess the level of innovation published in European Innovation Scoreboard.*
Findings: *The results of the research can be divided into two parts. In the first one the rankings of EU countries were built separately for each analyzed dimension of sustainable development and the area describing the level of innovation. In the second one the values of taxonomic measures of development were used to divide EU countries into groups characterized by similarity within all considered areas of sustainability. As a result, typological groups were obtained that differed both in number and composition.*
Practical Implications: *The presented results are important for individual countries as well as for organisations as EU, in which internal cohesion is one of the strategic development goals. The results can also used to assess the effects of implementing the assumptions of the "Green Deal" strategy, currently being developed in the EU.*
Originality/Value: *The added value of the paper is the research findings focused on the assessment of development of EU countries in two most important areas of functioning. In the literature, these areas are usually considered separately. In the paper, the authors decided to compare the results in these two areas analysed together and treat them as one of the important development directions of EU countries.*

Keywords: *Sustainable development, innovation, multi-criteria taxonomy methods.*

JEL classification: *C38, F63, O38, Q01.*

Paper Type: *Research study.*

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1. Introduction

In recent years, concepts such as sustainable development and innovation have become synonymous with the most important development directions of the countries of the world. The goal of most developed national economies is not only growth or economic development, but sustainable development and, as the experience shows in recent years, an increase in the level of innovation, in particular implemented towards the development of environmentally friendly technologies. In the literature, there are more and more frequently asked questions about how to combine these two research areas. According to Rammel (2003) "*... the notion of innovations must be a key-issue of sustainability*". Rennings (2000) emphasizes the issue of innovations as a crucial element of sustainability. Sarkar (2013) takes a holistic and strategic review on how the eco-innovations and their eco-specific promotional and developmental efforts are stimulating the sustainable development of eco-industries. While Seyfang and Smith (2007) indicate that "*innovation and community action are two important strands for sustainable development*" and "*they have not hitherto been linked*".

The strong relationship between sustainable development and innovation is also highlighted in many strategic documents. References to innovation as a tool to support sustainable development were already indicated in 1992 during the conference in Rio de Janeiro among the 27 general principles of global sustainable development included in the *"Declaration on the Environment and Development"*. The dissemination and transfer of technologies, including new and innovative technologies, has been indicated in this document as one of the measures that should be used to strengthen the institutional potential for sustainable development. In the newest strategy for sustainable development – The 2030 Agenda for Sustainable Development – innovation, industry and infrastructure are indicated as a main area of one of the sustainable goals' - Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. Volkery *et al*. (2006), looking for records about the relationship between sustainable development and innovation, analyzed 19 strategies for developing and developed countries. The result of their research is a number of useful insights, which show that the countries under study, both developed and developing, are still in the early stages of learning to use innovation towards effective action for sustainable development. One of the UK strategy for sustainable development – Securing the future states, which emphases that sustainable development should be pursued "*through a sustainable, innovative and productive economy*", can be also indicated as an example of relationships existing between these two areas (HM Government, 2005). It is worth emphasizing that the key elements of many definitions of sustainable development available in the literature (Sexton *et al*., 2008; Ciegis *et al*., 2009; Stafford-Smith *et al*., 2017; Abdikeey *et al*., 2018) are terms such as process and development, which emphasize the evolutionary nature of this phenomenon. Thus, when searching for connections between sustainable development and the development of innovation, it should be remembered that this is not only about innovations made as part of current development paths in response to the current market demand (Bromley, 1990), but also about innovations that will develop in alternative directions, ahead of the current needs of decision-makers or consumers (Rammel, 2003).

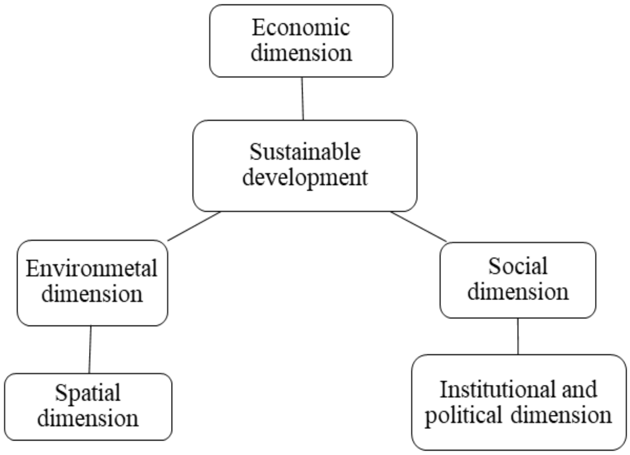
If we assume, in accordance with current trends in research on the relations between sustainable development and the development of innovation, that these areas are interrelated, then research that will not only theoretically describe this relationship will prove relevant. Therefore, the purpose of the paper is to present a comprehensive proposal for measuring the results achieved by selected global economies in the identified research areas: the progress in implementing the concept of sustainable development and the increasing the level of innovation. However, it should be emphasized that, unlike previous studies in this area, the authors of this work focus mainly on examining the results achieved in both these development concepts, but taking into account the dimensions and areas considered in their assessment, treated separately. This means that countries with similar results will be considered similar both in each of the distinguished dimensions of sustainable development (four dimensions have been identified in the paper) and in the areas considered in the innovation survey (four such areas were investigated).

The basis of empirical research, the results of which will be presented in this work, are the indicators used by the European Commission to monitor the progress in the implementation of the latest Strategy for Sustainable Development - Agenda 2030 and the indicators used to assess the level of innovation, published periodically by the European Commission in reports entitled European Innovation Scoreboard. Selected multidimensional statistical analysis methods were used to study the relationships between these areas, including multi-criteria taxonomy. The paper was divided into four parts. The firs one is devoted to the literature reviews in term of sustainable development and it relations with innovations. In second part the research procedure is presented. The third part concerns the study results and finally the conclusions end the paper.

2. Sustainable Development and Innovations – Where Is the Link?

Sustainable development has been in the spotlight of the representatives of various fields of science as well as economic practitioners (Schwab and Sala-i-Martin, 2012; Aiginger *et al*., 2013; Dordzhieva *et al*., 2018; Cheba, 2019; Kiba-Janiak, 2019; Zioło *et al*., 2019) for several decades. To this day, not only the way of defining this term has not been clearly specified. In the sphere of conceptualization, there are also issues related to measuring this phenomenon. According to the most well-grounded in the literature definition of this concept, which is derived from the Gro Harlem Brundtland Report (WCED, 1987), sustainable development is implemented "*to meet current needs without the risk that future generations will not be able to meet their needs*". Originally, in the neoliberal concept of sustainable development (*weak sustainability*) it was assumed that the foundations of this concept are created by separate dimensions society, environment and economy, and at their interface a common area describing sustainable development is created. In current approaches to defining and measuring this concept, the institutional and political dimension is also separated from the social dimension, and the environmental and spatial dimension (Figure 1).

Figure 1. *Dimensions of sustainable development*



Source: *Own elaboration based on Borys (2011).*

This approach to the visualization of this concept means that sustainable development becomes a more indefinite overarching or internal concept powered by its dimensions. The examples of such definition and the visualization of the concept of sustainable development can be found in Vera and Langlois (2007), Pawłowski (2008), Gunzenova and Nasibulina (2018), Szopik-Depczyńska *et al*. (2018), Cheba (2019). The proposed solutions and definitions are important to measure the progress in achieving sustainable development goals. In the initial period of interest in this concept, the links between the distinguished dimensions were relatively weak. This has strengthened the role of the economic dimension, mainly by ensuring the well-being of the growing middle and upper classes. As a result, the other two dimensions social and environmental, have been burdened with the negative consequences of this direction of development (Pezzey and Toman, 2002; Morandin-Ahuerma *et al*., 2019).

A dozen or so years after the Brundtland Report was published and environmental and social problems continued to increase on a global scale, the concept of strong sustainability appeared in 2002 (Giddings, 2002), and scientists undertook research into the limitations of both sustainable development models (Pezzey and Toman, 2002). The creators of the new concept have assumed that the natural environment is the central perspective for human socio-economic functioning. According to the authors of this paper, none of these concepts indicating the advantage of any of the dimensions that comprise the overall vision of sustainable development, is not appropriate, and these dimensions should be treated as equal and remaining in complex relationships. In view of current changes in the development of countries of the world, the progressive degradation of the natural environment and the lack of respect for human dignity still visible in some countries, the priority should not be given to any of them and they should be considered within the dynamic approach - as a process. In practice, this means that it is not possible to achieve a constant level of balance between all dimensions.

It should be emphasized that the current considerations on measuring this phenomenon were dominated by tendencies consisting in determining its average level (Siche *et al.*, 2008; Razminiene, 2019; Kuchmaeva *et al*., 2017; Proniewski and Zielińska, 2019). In some of them, the importance of individual strategic goals, to which indicators leading, operational and contextual (explanatory) ones, were assigned (Szopik-Depczyńska *et al*., 2018) was hierarchically established in the form of a pyramid. In these concepts, the relations between individual dimensions were basically ignored. Some symptoms of changes in the proposed measuring approaches can be seen only in the latest strategy. The 2030 Strategy for Sustainable Development Agenda 2030, in which, in addition to the fact that each of the 17 distinguished goals has been assigned appropriate indicators, other goals (and indicators) associated with them have also been listed. The interest of modern researchers is also aroused by the possibility of stimulating sustainable development by creating an innovative economy in its various fields (industry, agriculture, services). In such an economy it is possible to find new solutions for current and future social, health, ecological, educational problems. However, this is difficult to achieve if the country does not have adequate facilities, including material, financial and organizational ones, and human resources are characterized by a low level of qualifications.

The achievements of post-socialist countries of Central Europe (later integrated with the European Union) and Asian countries (Taiwan, South Korea, China and India) in the last thirty years have shown that despite these limitations, an economic success is possible. Of course, the mechanisms of accelerated economic development of both groups of countries were slightly different, but undoubtedly its basis was the modernization of the state, the improvement of the quality of human capital, foreign investment, transfer of new technologies and the construction of national and regional innovative systems. Innovation turned out to be an impulse for economic growth and development and improvement of the competitiveness of economies (Lacka, 2013).

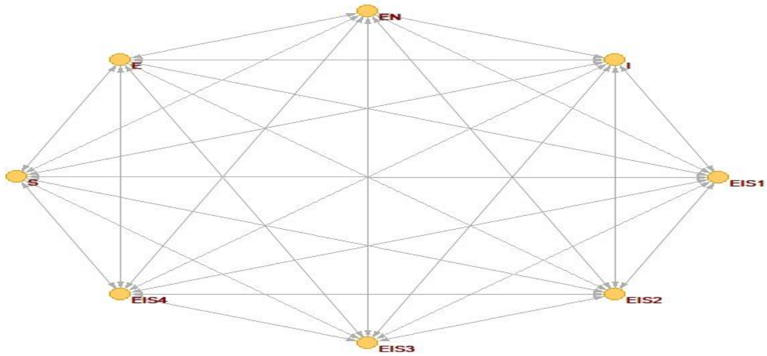
Research on the changes in the innovativeness and competitiveness of developing countries, that joined the European Union in the middle of the first decade of the 21st century shows that they depended on various determinants affecting the innovativeness of the economy. These factors were among others related to institutional and cultural aspects that affect the pillars of innovation (Lacka, 2015). It can be assumed that the same factors affect the possibilities of implementing the principles of sustainable development in all its aspects. On the other hand, the extent to which a given country is already involved in building the foundations for sustainable development determines its innovativeness (Fadhilah and Andriyansah, 2017; Cheba and Szopik-Depczyńska, 2019). This confirms the legitimacy of research on the relations connecting these economic categories.

The information presented so far shows that research in this area can be carried out from different points of view. With the appropriate research material available, it is possible to analyze, for example, the relationality of both areas, taking into account their changes over time. In this case, issues related to the investigation of cause-effect relationships between them are important. This means seeking answers to questions about which of the dimensions or areas stimulates the development of the other, whether innovation is the result of striving to ensure balance in socio-economic and environmental development, or vice versa.

However, taking into account the goal set in the paper regarding the study of progress in implementing the concept of sustainable development and striving to improve innovation, questions regarding the relationships connecting these areas and the results achieved by the examined objects (in this case EU countries) in each of the discussed dimensions and areas, considered separately and together are significant. It is worth emphasizing that these are not only the relations regarding the average level of the studied phenomena, but the relationships of dimensions and areas that make up each of them, i.e., the progress in social (S), economic (E), environmental (EN) and institutional and political (I) development in the case of sustainable development and the results achieved in each of the four areas taken into account when exemining innovation, framework conditions (EIS1), investments (EIS2), innovation activities (EIS3), impacts (EIS4). Graphically, the relations connecting these areas can be represented as follows (Figure 2).

In the presented network approach, individual dimensions of sustainable development and areas used to measure the level of innovation (collectively referred to as links) are equally important. Each of the links is considered in relation to all the others, and the direction of these connections is not always positive. The authors' research to date (Zioło *et al*., 2019) shows that negative relationships - meaning a decrease in, for example, the position taken by a given country within a link while increasing in another - can be observed in the case of relations occurring between the economic and environmental dimension of sustainable development. In the majority of the analyzed European countries, high results in terms of economic development are accompanied by definitely worse results in terms of environmental development. This means that economically more developed countries are more likely to create negative pressure on the environment. Similar relationships were also observed in this work, their detailed description is presented in the following parts of the work.

Figure 2. *The model of potential relationships between sustainable development and the innovativeness level*



Source: *Own.*

3. Research Procedure

3.1 Statistical Materials

The basis of empirical analyses presented in the work comprise two types of indicators for 2017. The indicators used by the European Commission to monitor progress in the implementation of the "Agenda for Sustainable Development 2030" in the European Union (Table 1) and the indicators used to assess the level of innovation of the EU countries published periodically by the European Commission in the European Innovation Scoreboard reports (Table 2).

Sustainable development indicators, as proposed in Cheba's work (2019), were divided into four orders; economic, social, environmental, and institutional and political ones, which was considered important in the case of the analyses carried out at the macroeconomic level. To each of the highlighted features the symbol $x_{i.j.}$ is assigned, where *i* is the number of the area in which the feature is located, while *j* is the number of the feature (Table 1). Moreover, their influence on the analyzed phenomenon through the classification of each attribute to a set of characteristics stimulating the development in a given area (symbol *S*) or destimulating it (symbol *D)* (Cheba, 2019).

Similarly, the indicators used to measure innovativeness at the country level were described, in which case the division used by the European Commission was applied. In total, 27 different indicators are used in EIS research; they are stimulants, i.e. features that positively influence the studied phenomenon. However, in the areas of sustainable development, destimulants dominate, accounting for about 53% of all indicators adopted for the study, with the majority of these features being in the social (81% of the features in this area) and environmental (73% of the features in this area) dimension.

Table 1. *List of indicators describing dimensions of sustainable development*

Symbol	**The economic area**	$\bar{x}$	***Vs***	***A***
$x_{1.1S}$	Agricultural factor income per annual work unit (AWU), chain linked volumes	0.391	53.294	1.098
$x_{1.2S}$	Government support to agricultural research and development, Euro *per capita*	0.129	173.345	2.640
$x_{1.3S}$	Area under organic farming, % of utilized agricultural area	0.342	72.898	1.028
$x_{1.4S}$	Employment rates of recent graduates, % of population aged 20 to 43	0.673	34.727	-1.362
$x_{1.5D}$	Inactive population due to caring responsibilities, % of inactive population aged 20 to 73	0.568	41.306	-0.380
$x_{1.6S}$	Real GDP per capita, chain linked volumes (2010), Euro *per capita*	0.267	81.319	1.476
$x_{1.7D}$	Young people neither in employment nor in education and training, % of population aged 15 to 38	0.627	39.399	-0.728
$x_{1.8S}$	Total employment rate, % of population aged 20 to 73	0.614	36.500	-0.829
$x_{1.9S}$	Investment share of GDP by institutional sectors, % of GDP	0.628	36.035	-0.565
$x_{1.10D}$	People killed in accidents at work, number per 100,000 employees	0.649	35.888	-0.601
$x_{1.11S}$	Gross domestic expenditure on R&D, % of GDP	0.369	80.978	0.753
$x_{1.12S}$	Total employment in high- and medium-high technology manufacturing sectors and knowledge-intensive service sectors, % of total employment	0.541	42.609	-0.182
$x_{1.13S}$	R&D personnel, % of active population	0.449	59.154	0.148
$x_{1.14S}$	Purchasing power adjusted GDP *per capita*, real expenditure *per capita* (in PPS)	0.248	80.058	2.155
$x_{1.15S}$	Resource productivity and domestic material consumption (DMC), Euro per kilogram, chain linked volumes (2010)	0.353	73.557	0.795
$x_{1.16D}$	General government gross debt, % of GDP	0.649	33.952	-0.996
$x_{1.17D}$	Shares of labor taxes in total tax revenues, % of total taxes	0.499	55.021	0.263
Symbol	**The social area**	$\bar{x}$	***Vs***	***A***
$X_{2.1D}$	Severely materially deprived people, %	0.770	29.868	-1.813
$x_{2.2D}$	People at risk of poverty or social exclusion, %	0.602	39.950	-0.831

$x_{2.3\,D}$	People at risk of income poverty after social transfers, %	0.463	58.047	-0.129
$x_{2.4\,D}$	People living in households with very low work intensity, % of total population aged less than 78	0.646	41.410	-0.777
$x_{2.5\,D}$	In work at-risk-of-poverty rate, % of employed persons aged 18 or over	0.609	36.620	-0.679
$x_{2.6D}$	Population living in a dwelling with a leaking roof, damp walls, floors or foundation or rot in window frames of floor, %	0.590	39.900	-0.756
$x_{2.7S}$	Life expectancy at birth, years	0.615	51.065	-0.826
$x_{2.8\,S}$	Self-perceived health, very good or good, %	0.590	43.060	-0.941
$x_{2.9\,D}$	Death rate due to chronic diseases, number per 100,000 persons aged less than 65	0.670	43.899	-1.056
$x_{2.10\,D}$	Death rate due to tuberculosis, HIV and hepatitis, number per 100,000 persons	0.784	31.918	-1.690
$x_{2.11D}$	Self-reported unmet need for medical care by detailed reason, % of population aged 16 and over	0.793	29.673	-2.138
$x_{2.12D}$	Total early leavers from education and training, % of population aged 18 to 33	0.585	44.571	-0.853
$x_{2.13\,S}$	Total tertiary educational attainment, % of population aged 30 to 43	0.498	56.125	-0.143
$x_{2.14\,S}$	Participation in early childhood education, % of the age group between 4-years-old and the starting age of compulsory education	0.690	37.747	-1.167
$x_{2.15\,S}$	Adult participation in learning, % of population aged 25 to 73	0.349	74.814	1.009
$x_{2.16\,D}$	Final energy consumption in households per capita, kg of oil equivalent	0.565	39.404	-0.223
$x_{2.17\,D}$	Population unable to keep home adequately warm, %	0.790	33.225	-1.692
$x_{2.18\,D}$	Long-term unemployment rate, % of active population	0.837	23.483	-2.977
$x_{2.19\,D}$	Relative median at-risk-of-poverty gap, % distance to poverty threshold	0.577	45.319	-0.485
$x_{2.20\,D}$	Income distribution, quintile share ratio	0.676	37.317	-0.891
$x_{2.21\,D}$	Total overcrowding rate, %	0.431	62.610	0.255
$x_{2.22\,D}$	Income share of the bottom 40% of the population, %	0.649	51.744	-0.700
$x_{2.23\,D}$	Total population living in households considering that they suffer from noise, %	0.566	49.570	-0.476

$x_{2.24\,D}$	People killed in road accidents, rate	0.623	40.813	-0.740
$x_{2.25\,D}$	Death rate due to homicide, number par 100,000 persons	0.792	27.594	-2.542
$x_{2.26\,D}$	Population reporting occurrence of crime, violence or vandalism in their area, %	0.628	33.353	-1.096
Symbol	**The environmental area**	$\bar{x}$	***Vs***	***A***
$x_{3.1D}$	Ammonia emissions from agriculture, kilograms per hectare	0.787	28.640	-1.901
$x_{3.2D}$	Primary energy consumption, million tonnes of oil equivalent (TOE)	0.815	30.659	-2.024
$x_{3.3D}$	Final energy consumption, million tonnes of oil equivalent (TOE)	0.819	29.425	-2.033
$x_{3.4S}$	Energy productivity, Purchasing Power Standard (PPS) per kilogram of oil equivalent	0.293	67.421	1.542
$x_{3.5S}$	Share of renewable energy in gross final energy consumption, %	0.293	83.496	1.082
$x_{3.6D}$	Energy dependence, % of imports in total energy consumption	0.471	52.120	0.149
$x_{3.7S}$	Recycling rate of municipal waste,% of total waste generated	0.512	46.184	-0.158
$x_{3.8D}$	Average CO2 emissions per km from new passenger cars, g CO2 per km	0.485	55.720	0.228
$x_{3.9D}$	Greenhouse gas emissions - tonnes *per capita*	0.645	35.586	-0.725
$x_{3.10D}$	Greenhouse gas emissions intensity of energy consumption, index (2000 = 100)	0.485	45.599	0.063
$x_{3.11D}$	Shares of environmental in total tax revenues, % of total taxes	0.578	46.185	-0.185
Symbol	**The political and institutional area**	$\bar{x}$	***Vs***	***A***
$x_{4.1S}$	Seats held by women in national parliaments, %	0.486	51.513	0.155
$x_{4.2\,S}$	Seats held by women in national governments, %	0.524	44.502	0.069
$x_{4.3\,S}$	Positions held by women in senior management positions, board members, %	0.389	66.728	0.462
$x_{4.4\,S}$	Positions held by women in executives management positions, %	0.419	53.393	0.770
$x_{4.5\,S}$	General government total expenditure on law courts, Euro per inhabitant	0.289	78.029	1.281
$x_{4.6\,S}$	Population with confidence in EU institutions: European Parliament, %	0.560	47.028	-0.321

$x_{4.7\ S}$	Population with confidence in EU institutions: European Commission, %	0.635	39.991	-0.538
$x_{4.8\ S}$	Population with confidence in EU institutions: European Central Bank, %	0.470	46.357	0.385
$x_{4.9\ S}$	Official development assistance as share of gross national income,% of gross national income (GNI)	0.256	113.826	1.339
$x_{4.10\ S}$	EU imports from developing countries, million EUR *per capita*	0.046	404.399	5.217

Source: *Cheba (2019) based on Eurostat (2018), where:* $\bar{x}$ *– mean value,* V_s *– coefficient of variation, A – asymmetry.*

Table 2. *List of indicators describing areas of innovation level*

Symbol	Framework conditions	$\bar{x}$	*Vs*	*A*
$x_{1.1S}$	New doctorate graduates	0.435	60.085	0.531
$x_{1.2S}$	Population completed tertiary education	0.501	56.474	0.023
$x_{1.3S}$	Lifelong learning	0.363	74.602	0.742
$x_{1.4S}$	International scientific co-publications	0.388	74.495	0.550
$x_{1.5S}$	Scientific publications among top 10% most cited	0.463	62.965	0.177
$x_{1.6S}$	Foreign doctorate students	0.314	90.697	0.908
$x_{1.7S}$	Broadband penetration	0.446	52.751	0.364
$x_{1.8S}$	Opportunity-driven entrepreneurship	0.386	64.576	0.851
Symbol	**Investments**	$\bar{x}$	***Vs***	***A***
$x_{2.1S}$	R&D expenditure in the public sector	0.460	67.871	0.249
$x_{2.2\ S}$	Venture capital investments	0.402	75.676	0.671
$x_{2.3\ S}$	R&D expenditure in the business sector	0.394	75.075	0.701
$x_{2.4\ S}$	Non-R & D innovation expenditure	0.320	72.261	1.000
$x_{2.5\ S}$	Enterprises providing ICT training	0.502	50.267	-0.171
Symbol	**Innovation activities**	$\bar{x}$	***Vs***	***A***
$x_{3.1S}$	SMEs with product or process innovations	0.511	60.270	-0.366
$x_{3.2S}$	SMEs with marketing or organizational innovations	0.494	56.680	-0.107
$x_{3.3S}$	SMEs innovating in-house	0.521	58.988	-0.328

$x_{3.4S}$	Innovative SMEs collaborating with others	0.435	62.616	0.393
$x_{3.5S}$	Public-private co-publications	0.430	58.617	0.449
$x_{3.6S}$	Private co-funding of public R&D expenditures	0.464	50.293	0.151
$x_{3.7S}$	PCT patent applications	0.278	102.588	1.254
$x_{3.8S}$	Trademark applications	0.389	66.887	1.176
$x_{3.9S}$	Design applications	0.353	76.371	0.528
Symbol	**Impacts**	$\bar{x}$	***Vs***	***A***
$x_{4.1S}$	Employment in knowledge-intensive activities	0.451	53.092	0.412
$x_{4.2S}$	Employment fast-growing firms innovative sectors	0.533	49.570	0.016
$x_{4.3S}$	Medium & high tech product exports	0.618	38.475	-0.466
$x_{4.4S}$	Knowledge-intensive services exports	0.479	56.280	0.253
$x_{4.5S}$	Sales of new-to-market and new-to-companies innovations	0.366	75.649	0.631

Source: *own elaboration on the basis of EIS (2017), where:* $\bar{x}$ *- mean value,* V_s *- coefficient of variation, A – asymmetry.*

The initial analysis of diagnostic features shows that there are large disproportions between the surveyed countries in terms of sustainable development. This is indicated by high values of the variation coefficient (V_s) and the asymmetry coefficient (A). The first of these parameters is in the range of 23.5% to 404.4%, with every third feature characterized by differentiation above 50%. The consequence of high dispersion of features is also their high asymmetry. It should be noted that left-hand asymmetry dominates, which means that for most EU countries the values of the features are above the EU average, which is positive regarding features that positively influence the studied phenomenon, and negative in the case of destimulants.

The highest level of diversity and asymmetry measures is characterized by the feature $x_{4.10\ S}$ - EU imports from developing countries by country income groups, million EUR *per capita*, where the asymmetry factor exceeds 400% and the asymmetry measure is 5,217, which indicates very strong right-hand asymmetry. Research on the level of innovation in EU countries also indicates the existence of significant disproportions between the analyzed countries, which is confirmed by high values of the coefficient of variation and the asymmetry coefficient. The highest level of differentiation (over 90%) was characterized by two features: $x_{3.7S}$ – PCT patent applications (102.588%) and $x_{1.6S}$ – foreign doctorate students (90.697%).

The differentiation below 50% also concerned two features: $x_{4.3S}$ – medium and high tech product exports (38.475%) and $x_{4.2S}$ – employment in fast-growing companies in innovative sectors (49.570%). It is worth noting that only in the case of five indicators their distribution is characterized by at most a moderate negative (left-sided) asymmetry, which means that in the case of most countries the values of these features are above average. In other cases, there is asymmetry with the opposite sign (right-sided), regarding most features at least of moderate strength.

3.2 Description of Statistical Methods

To assess the situation of EU countries in terms of all dimensions of sustainable development taken into account in the study and areas describing the level of innovation of the European Union countries, a two-stage research procedure was used. In the first stage for each of the distinguished dimensions and areas, the taxonomic measure of development was calculated. For this purpose the following formula was applied (Nowak, 1990):

$$z_i = \frac{1}{K}\sum_{k=1}^{K} z_{ik} \tag{1}$$

where: z_i – the value of the taxonomic development measure for *i*-th object, z_{ik} – normalized value of *i*-th indicator in *k*-th object, K – the number of considered indicators.

For the normalization of diagnostic indicators, the zero unitarisation method proposed by Kukuła (2000), was applied:

for stimulant $$z_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \qquad \max_i x_{ij} \neq \min_i x_{ij}, \tag{2}$$

for destimulant $$z_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\max_i x_{ij} - \min_i x_{ij}}, \qquad \max_i x_{ij} \neq \min_i x_{ij}, \tag{3}$$

In the second stage to separated countries similar in terms of each distinguished dimensions and areas the multi-criteria taxonomy method was used. The detailed description of this method can be found in the following papers: Zopounidis and Doumpos (2000), Bąk and Cheba (2019). The basis for this method are **DK** distance matrices defined for each of the distinguished dimensions and areas of $K_l(l = 1, \ldots, r)$. On the basis of the values in the distance matrix, a threshold value *d* should be defined. The following formula can be utilized for this goal:

$$distance = \underset{j=1,2,\ldots,m}{\text{med}} \left|x_{ij} - x_{kj}\right|. \tag{4}$$

In the next step the transformation of the **DK** distance matrices is carried out. For each classification criterion, a **CK** affinity matrix of dimension $(n \times n)$ is defined. The elements of this matrix: $c_{ij}^{K}(i,j = 1,...,n)$ are equal to:

$$c_{ij}^{K} = 1 for d_{ij} \leq d \quad (5a), \qquad c_{ij}^{K} = 0 for d_{ij} > d \quad (5b)$$

If inequality (5a) is satisfied, the objects designated as *i* and *j* are treated as similar. Alternately, if inequality (5b) is satisfied, the analyzed objects are deemed as dissimilar. In the second case, the affinity measure of c_{ij} is equal to zero. The final step of this method is devoted to determination of **C** $_{(n \times n)}$ affinity matrix according to the following formula:

$$c_{ij} = \prod_{K=1}^{r} \quad c_{ij}^{K}. \qquad (6)$$

in which the c_{ij} elements of the **C** matrix are equal to the product of the relevant elements of the **CK** matrix for all the analyzed criteria. If $c_{ij} = 1 \ (i,j = 1,...,n)$, then each of the corresponding c_{ij}^{K} elements in the **CK** matrices are equal to one. At the same time, $c_{ij} = 0$ if one of the c_{ij}^{K} elements corresponding to it is equal to zero.

Finally, two objects (two EU countries) are considered to be similar to one another in terms of all the dimensions or areas considered simultaneously if they are similar to one another separately taking into account each of those dimensions and areas considered separately and opposite, two objects are treated as dissimilar with respect to all the examined dimensions and areas if they are not similar to one another even with regard to one such criterion. It is also the main reason of a large number of small-sized groups (one- and two-element groups) which can be obtained as the result of this method. The result of this method is the division of EU countries into typological groups. In the literature (Wawrzyniak, 2012) the *vector elimination method* is frequently proposed for this purpose. The detailed description of this method based on the **C***$_{(n \times n)}$ dissimilarity matrix calculated on the basis of **C**$_{(n \times n)}$ affinity matrix can be found in many scientific papers such as: Malina (2004), Bartelet and Larnersdorf (2009). It should be noted that the typological groups in this method are separated according to their size. It means that the first typological group is the most numerous. While the last one, is usually formulated only by one country.

4. Study Results

The research included all diagnostic features, which are presented in Tables 1 and 2. The authors are aware that some features may be highly correlated, which means duplicating the same information. In the literature on the subject, two alternative solutions are proposed. The first of them recommends using formal-statistical selection, which allows to remove strongly correlated features from the set. The second one indicates that in the case of analyzes regarding e.g. strategic development directions of the countries of the world, for which the established list of monitoring indicators is the result of the work of expert teams appointed for this purpose, the use of statistical methods for the selection may distort the results of the survey. In this work, the second approach was adopted; hence all the features, i.e. 64 regarding sustainable development and 27 characterizing the level of innovation were qualified for the study.

In the first stage of the study, based on the values of normalized indicators in accordance with formulas: 2 and 3, the rankings of EU countries were built separately for each analyzed dimension of sustainable development and the area describing the level of innovation. The results of this stage of the study are presented in Tables 3-4. In this case, the significant diversity of positions taken by individual countries in the various dimensions and areas adopted for the study is worth emphasizing.

Table 3. *Comparison of results within individual dimensions of sustainable development and areas of innovation in 2016*

EU countries:	E		S		EN		IP	
	1	2	1	2	1	2	1	2
Austria	0.583	6	0.705	10	0.625	5	0.375	14
Belgium	0.516	11	0.685	13	0.563	15	0.547	7
Bulgaria	0.356	25	0.379	27	0.519	22	0.412	10
Croatia	0.329	26	0.552	23	0.579	12	0.322	21
Cyprus	0.359	24	0.662	14	0.362	28	0.203	26
Czech Republic	0.532	9	0.734	7	0.603	7	0.193	27
Denmark	0.639	2	0.752	4	0.761	1	0.610	4
Estonia	0.478	13	0.610	19	0.567	14	0.383	12
Finland	0.558	8	0.762	2	0.657	3	0.635	3
France	0.509	12	0.736	6	0.532	20	0.457	8
Germany	0.628	3	0.661	15	0.435	26	0.547	6
Greece	0.257	28	0.444	25	0.539	18	0.129	28
Hungary	0.436	16	0.555	22	0.574	13	0.272	25
Ireland	0.521	10	0.762	3	0.624	6	0.407	11
Italy	0.360	23	0.562	20	0.523	21	0.375	15
Latvia	0.406	19	0.437	26	0.584	10	0.359	17
Lithuania	0.413	18	0.482	24	0.602	8	0.422	9
Luxembourg	0.621	4	0.700	11	0.539	19	0.582	5
Malta	0.462	15	0.714	9	0.417	27	0.299	22
Netherlands	0.612	5	0.752	5	0.499	24	0.698	2
Poland	0.378	22	0.632	16	0.480	25	0.297	23
Portugal	0.398	21	0.559	21	0.586	9	0.356	18
Romania	0.285	27	0.371	28	0.637	4	0.381	13
Slovakia	0.415	17	0.621	18	0.582	11	0.290	24

Slovenia	0.468	14	0.716	8	0.560	16	0.352	20
Spain	0.401	20	0.625	17	0.514	23	0.354	19
Sweden	0.683	1	0.777	1	0.731	2	0.785	1
United Kingdom	0.566	7	0.699	12	0.542	17	0.368	16

Source: *Own calculations where: 1 - the value of taxonomic measure of development calculated for each dimensions of sustainable development and area of innovations level. 2 - position in the ranking.*

Table 4. *Comparison of results within individual dimensions of sustainable development and areas of innovation in 2016*

EU countries:	IN1		IN2		IN3		IN4	
	1	2	1	2	1	2	1	2
Austria	0.558	8	0.626	5	0.709	2	0.452	16
Belgium	0.610	7	0.631	4	0.683	4	0.459	15
Bulgaria	0.120	28	0.179	27	0.189	24	0.320	24
Croatia	0.130	27	0.350	18	0.268	22	0.223	27
Cyprus	0.302	18	0.234	24	0.438	13	0.416	19
Czech Republic	0.281	20	0.410	13	0.364	19	0.620	7
Denmark	0.798	1	0.580	7	0.657	7	0.504	12
Estonia	0.329	15	0.404	14	0.331	20	0.394	20
Finland	0.372	14	0.379	16	0.283	21	0.474	14
France	0.640	6	0.660	3	0.689	3	0.480	13
Germany	0.524	10	0.600	6	0.505	11	0.614	8
Greece	0.390	13	0.711	2	0.711	1	0.673	3
Hungary	0.312	17	0.242	23	0.404	16	0.268	26
Ireland	0.248	22	0.321	19	0.183	25	0.637	6
Italy	0.528	9	0.434	11	0.509	9	0.878	1
Latvia	0.294	19	0.291	21	0.425	14	0.443	18
Lithuania	0.223	24	0.316	20	0.158	27	0.353	22
Luxembourg	0.313	16	0.397	15	0.410	15	0.194	28
Malta	0.674	4	0.490	10	0.583	8	0.641	5
Netherlands	0.262	21	0.198	26	0.402	17	0.516	11
Poland	0.727	3	0.542	9	0.668	6	0.611	9
Portugal	0.169	25	0.290	22	0.160	26	0.385	21
Romania	0.427	12	0.366	17	0.396	18	0.321	23
Slovakia	0.160	26	0.064	28	0.074	28	0.301	25
Slovenia	0.246	23	0.214	25	0.209	23	0.650	4
Spain	0.436	11	0.425	12	0.471	12	0.452	17
Sweden	0.793	2	0.743	1	0.671	5	0.610	10
United Kingdom	0.672	5	0.545	8	0.505	10	0.811	2

Source: *Own calculations where: 1, 2 and 3 as in Table 3.*

In principle, we can only talk about a relatively even and high level of development in the case of Scandinavian countries Denmark and Sweden, which have managed to permanently separate the economic growth from the negative pressure on the environment, while achieving high results in the case of innovation research. The situation of some countries located in the south and east of Europe is interesting, e.g., of Croatia, Portugal and Romania achieving significantly higher results in the case of the environmental dimension of sustainable development and lower in terms of the development in social and economic dimensions. In this case, a smaller environmental degradation is the result of a slower economic development. A similar situation also applies to areas of innovation. The results of these countries in this respect are also the lowest among the surveyed EU countries.

The development paths of most of the highly developed European countries show that along with the economic development environmental degradation occurs. Only at a sufficiently high level of economic development is the interest in environmentally friendly solutions growing. The opportunity to use the experience of these countries, and the awareness of the importance of environmental problems for further safe human functioning should also induce less developed countries to seek environmentally- and society-friendly solutions. The basis in this case is the general level of innovation assessed in most cases taking into account the solutions caring for the environment and humans.

In the second stage, the values of taxonomic measures of development were used to divide EU countries into groups characterized by similarity within all considered areas of sustainable development (the first variant of analysis - V1), the areas of innovation (the second variant of analysis - V2) and jointly, considering all dimensions and areas mentioned above (the third variant of analysis - V3). As a result, typological groups were obtained that differed both in number and composition (Table 5). It is worth emphasizing that the order of groups depends on their size, and not on the achieved results.

In the course of the analysis the obtained results, it is worth paying attention to significant differences in the classification of the surveyed EU Member States due to their level of sustainable development (V1) and the level of innovativeness (V2). In both cases, three single-element groups were separated, but only Estonia formed a separate group twice. Regardless of the studied area, a similar level of development is noted for such countries as: a) Belgium and Luxembourg, b) Denmark and Finland, c) Spain, Poland, Portugal and Slovakia. These countries (the exception is Spain) were classified into the same typological groups, in view of the results in the scope of the analyzed dimensions of sustainable development, the areas of the level of innovation considered separately (V1 and V2) and jointly (V3). The influence of geographical proximity on the classification results is clearly visible here. One group includes, for example, Scandinavian countries (Denmark and Finland).

The combined consideration of diagnostic features also allowed to distinguish four one-element groups for: Malta, Estonia, Germany and Bulgaria. It is worth noting that Bulgaria, whose results in terms of dimensions of sustainable development were among the lowest, in the last adopted variant of classification comparing jointly the results in terms of sustainable development and the level of innovation (V3) formed a separate typological group. Also noteworthy is the classification of Germany, which in the case of the level of innovation formed a separate typological group. It also influenced the results of qualifying this country in the third variant and the creation of a separate typological group by this country for the second time.

Table 5. *Typological groups of EU countries due to sustainable development and the level of innovation*

Group	Sustainable development (V1)	Innovation level (V2)	Sustainable development and innovation level (V3)
I	Czech Republic, Ireland, Spain, France Austria, Poland, Portugal, Slovenia, Slovakia	Bulgaria, Greece, Spain, Latvia, Poland, Romania, Portugal, Slovakia, Hungary	Latvia, Hungary, Poland, Portugal, Romania, Slovakia
II	Croatia, Latvia, Lithuania, Hungary, Romania	Austria, Denmark, Finland, Netherlands, Sweden	Spain, France, Italy, United Kingdom
III	Denmark, Netherlands, Finland, United Kingdom	Belgium, France, Ireland, Luxembourg, United Kingdom	Denmark, Netherlands, Finland, Sweden
IV	Cyprus, Malta	Croatia, Cyprus, Slovenia, Italy	Belgium, Luxembourg, Austria
V	Belgium, Germany, Luxembourg	Czech Republic, Greece, Lithuania	Croatia, Cyprus, Slovenia
VI	Greece, Italy	Malta	Greece, Lithuania
VII	Sweden	Estonia	Czech Republic, Ireland
VIII	Estonia	Germany	Malta
IX	Bulgaria		Estonia
X			Germany
XI			Bulgaria

Source: *Own calculations.*

5. Discussion and Conclusions

One of objectives of this article was to examine whether the proposed methodology for dividing EU regions due to the level of sustainable development and the level of innovativeness reflects well the diversity of these regions within the analyzed area. The starting point were normalized values of indicators measuring the level of innovation of EU countries on the basis of which the research is conducted, and the results of which are presented cyclically in the European Innovation Scoreboard reports, as well as the indicators used by the European Commission to monitor progress in the implementation of the *"Agenda for Towards Sustainable Development 2030"*. The method, which allows for the identification of the countries similar in terms of all the highlighted areas discussed in the paper, but treated separately, is the multi criteria taxonomy. Its application allows to indicate countries achieving similar results in each of the highlighted areas of sustainable development and the level of innovation. It also avoids the situation in which the level of development of the analyzed countries could be determined by the average results obtained on the basis of all these areas, whereas this approach dominates in the studies of the level of socio-economic development of various entities. High diversity of these entities in different areas, as in the case of sustainable development (Table 1) and the level of innovation (Table 2) may lead to distortion of the obtained results.

The results of the analysis presented in the article are important not only for individual countries, but primarily for organizations such as the European Union, in which internal cohesion is one of the strategic development goals. Economic development, even in an economy based on knowledge and innovation, takes place at the expense of the natural environment and its values. Humanity began to realize that it is necessary to change the current economic models - focused on permanent economic growth, progressive consumption, and the perception of prosperity only in the form of increasing indicators of economic growth and consumption. The disastrous ecological, social and political effects of such behavior must be taken into account when creating mechanisms for the development of economies, which should be based on creating conditions for sustainable development in the mega-, macro- and mesoscale (at the level of the world, country and region). They will help to reduce environmental degradation. This approach promotes innovation and requires searching for new, more effective manufacturing solutions that will reduce negative externalities in the sphere of production, distribution and consumption. It will also help to improve the competitiveness of enterprises, both on domestic and foreign markets. This means that the need for environmental protection and sustainable development assumptions are a carrier of technical progress and innovation (Kożuch, 2017).

Therefore, it is considered reasonable to conduct research towards the identification of similar countries in all analyzed areas, which includes the overall assessment of sustainable development and innovation in EU countries, as done in this article. The results of this research can be used to assess the effects of implementing the assumptions of the "Green Deal" strategy currently being developed in the European Union. Its creators aim to achieve sustainable development of Community countries through investments in ecological technologies that will enable them to increase entrepreneurship, prosperity and improve the quality of life of citizens while respecting the natural environment.

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