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Contact to corresponding author: Magdalena Tutak, magdalena.tutak@polsl.pl

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Jarosław Brodny
Silesian University of Technology, Poland
orcid.org/0000-0002-6807-4431

Magdalena Tutak
Silesian University of Technology, Poland
orcid.org/0000-0003-4781-8697

The level of implementing sustainable development goal "Industry, innovation and infrastructure" of Agenda 2030 in the European Union countries: Application of MCDM methods

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Keywords: *sustainable development; innovativeness; EU–27; MCDM methods*

Abstract

Research background: Sustainable development of the modern world represents an opportunity to preserve economic growth and technological progress, as well as social development, without limiting the possibilities of this development for past generations. The directions of this development are included in the 17 goals and 169 tasks of the 2030 Agenda for Sustainable Development. The achievement of these goals and the implementation of the adopted

tasks is a huge challenge for individual countries and regions. This also applies to the European Union (EU), where economic development is closely linked to environmental protection and social inclusion. Of key importance in this context is Objective 9 of Agenda 2030, and thus its level of implementation in the EU-27 countries is the aim of the research presented in this paper.
Purpose of the article: The research involved assessing the level of EU countries in terms of building stable infrastructure, promoting sustainable industrialization and fostering innovation, i.e., the main areas of Goal 9 of Agenda 2030.
Methods: The assessment was based on the EU–27 countries' sustainable development index (SDG9) determined with the use of 14 indicators characterizing these areas between 2015–2020. The basis of the developed methodology was a multi criteria decision making approach (MCDM methods). TOPSIS, WASPAS and EDAS methods were used to determine the sustainability index, and the Entropy, CRITIC and standard deviation (SD) methods were used to determine weights for the adopted indicators. In addition, the use of the Spearman's and Kendall's Tau non-parametric tests enabled the analysis of the relationship between the SDG9 index and the basic economic, environmental and energy parameters, as well as the digitalization of the countries under study.
Findings & value added: The results show that the EU–27 countries vary widely in terms of implementing Sustainable Development Goal 9 of Agenda 2030 over the analyzed period. Now, the most advanced in this respect are Denmark, Germany, Luxembourg, the Netherlands, Finland, and Sweden. By contrast, substantial problems are found in Bulgaria, Greece, Portugal, and Lithuania. The results also provide an opportunity to trace changes in the value of the designated index in individual countries, and in groups of countries of the "old" and "new" EU. These results significantly enrich the knowledge of the effectiveness of implementing Goal 9 of Agenda 2030 in the EU–27 countries and the relationship between the development of individual countries and sustainable development economy. These findings can also be used to create new EU–27 strategies for sustainable and solidarity-based development of the whole EU. In addition, the results can be helpful to decision-makers as they highlight important indicators related to innovation, industrialization and infrastructure that should be considered when formulating a country's sustainable development strategy. The added value of the study is the research procedure presented, which can be used in analyses on the study of various issues related to sustainable development for other groups of regions.

Introduction

Sustainable socioeconomic development is characterized by the fact that while meeting the needs of modern societies, it will not limit the development opportunities of future generations (Barbier, 1987). This new approach to development has been defined as a process that seeks to ensure that current social needs are met, while respecting the requirements of environmental protection — without jeopardizing the livelihoods of future generations. An important element of this approach is also to reduce, and where possible eliminate, the imbalance between economic growth and social development, and between socio-economic development and the environment. This issue, in the context of the consumption of environmental resources, the increase in consumption and the widening disparity in the quality of life of the inhabitants of developed and developing countries, was already recognized 30 years ago at the 1992 Earth Summit in Rio de Janeiro, when the principles contained in the "Global Action Agenda — Agenda 21 (United Nations, 1992) were adopted. Twenty years later, in 2012, at the United Nations (UN) Conference on Sustainable Development in Rio de Janeiro, the UN integrated the process to develop a set of new goals, the so-called Agenda 2030 goals for sustainable development (Le Blanc, 2015).

One of the 17 goals included in this Agenda is Goal 9: "Industry, innovation and infrastructure," the implementation of which is expected to influence the construction of stable infrastructure, promote sustainable industrialization, and foster innovation. While the components of this goal contribute to economic growth, their impact varies depending on a country's stage of development (Haraguchi *et al.*, 2017; Raszkowski & Bartniczak, 2019). For example, industrial development in developed economies depends on the degree of adoption of new technologies and smart production processes (Ringel *et al.*, 2016). For developing economies, on the other hand, industrialization means the structural transformation of the economy from traditional sectors, such as mining, agriculture and fishing, to modern manufacturing industries based on innovation and modern technologies (Szirmai, 2012). It is also assumed that without technology and innovation there will be no industrialization, and without industrialization there will be no sustainable development. Any measures taken for this development will not be effective if national governments and societies do not jointly ensure that infrastructure is properly developed, and that industry is remodeled in such a way that it becomes environmentally and socially friendly. For such a development model, investment in sectors that are fundamental to achieving the Sustainable Development Goals, including new technologies, is crucial. In the context of climate change alone, a great deal of new and groundbreaking innovation is needed to develop technologies linked to the renewable energy sector, among other areas (Adenle *et al.*, 2015).

As part of the implementation of Goal 9 "Industry, innovation and infrastructure" of the 2030 Agenda, countries should carry out activities to support sustainable industrialization, which will be based on innovation and adequate infrastructure. This means that innovation and creativity, industry and infrastructure play a key role for the sustainable development of the world's economies, including the EU countries. However, innovation and new technologies used in industry require knowledge in the broadest sense, because only this leads to efficient use of resources, which is the basis of a sustainable economy (Javaid *et al.*, 2022; Skvarciany *et al*., 2021). In order for these processes to take place, it is necessary to systematically expand the scope of scientific research, the creation of patents, an increase in the number of employees engaged in research and development and the number of university graduates, especially those with technical profiles (Olaoye *et al*., 2021; Sokolov-Mladenović *et al*., 2016). At the same time, expenditures on research and development must systematically increase. The involvement of the private sector in the implementation of innovative solutions that generate added value for the economy is also of great significance (Szopik-Depczyńska *et al*., 2018). This is because new technological solutions appearing on the market encourage companies to invest, as one of the directions to achieve competitive advantage. These activities can result in lowering energy intensity or reducing the use of natural resources for the production of goods, as well as many other benefits that support the environment and humans, thereby strengthening sustainable development.

The importance of innovation, modern industry and infrastructure and their relationship to the concept of sustainable development has been recognized for many years in the EU. The stabilizer of economies and the driver of sustainable development, in the context of the EU's most important long-term strategy — the European Green Deal, is and will be an industry based on new, innovative solutions that foster the so-called low-carbon economy. Linked to this strategy is an industrial strategy to enable the EU to achieve a twofold transformation — green and digital, to make the EU industry more globally competitive and to increase Europe's open strategic autonomy. Therefore, the goal of this strategy is to support industry as a catalyst for change, innovation and growth. The EU assumes that the development of modern European industry will guide the entire transformation process toward climate neutrality. This is a bold assumption, as there is a simultaneous overlap between two concepts, Industry 4.0 and the European Green Deal. Their interaction, and in fact their synergy, should ensure the synergistic, sustainable development of the EU, which should result in building an innovative knowledge-based and environmentally neutral economy.

In this context, it is reasonable to conduct a study to assess the level of innovation, sustainable industrialization and infrastructure in the EU countries to date, which are closely related to the implementation of Goal 9 of Agenda 2030 for sustainable development.

These topics are extremely important both from a scientific and practical point of view, as they concern an important and topical issue, as well as from economic and social perspectives. Previous publications, devoted to the issues of sustainable development of the EU countries provide a lot of information related to the concept of sustainable development in the field of energy and climate protection (Kılkış, 2016; Gródek-Szostak *et al.*, 2020), no poverty (Sobczak *et al.*, 2021), sustainable cities and communities (MacDonald *et al.*, 2020), and responsible consumption and production (Gunawan *et al.*, 2020). However, the literature lacks comprehensive analyses related to the implementation of Goal 9 of Agenda 2030 by individual member countries, which indicates a research gap regarding this issue. The existing literature has devoted a lot of space to the problem of innovativeness in individual countries, including those of the EU (Beynon *et al.*, 2023; Roszko-Wójtowicz *et al.*, 2022; Xu *et al.*, 2023), but has not addressed the other problems included in Goal 9 of the UN Agenda 2030, namely industrialization and infrastructure development. This study considers all the areas included in this goal, which provides an opportunity for its comprehensive evaluation, consistent with the purpose of the work presented here.

In order to fill this gap and expand knowledge of the level of innovation, sustainable industrialization and infrastructure development in the EU countries, a study was conducted, the results of which are presented in this paper. Their main objective was to assess the level of innovation, sustainable industrialization and infrastructure in the EU countries between 2015-2020, taking into account the pace and effectiveness of the changes implemented.

This topic led the authors to formulate research questions, which clarify the subject and scope of the research, organize the course of the research, as well as make it possible to analyze the results, formulate final conclusions as well as limitations and directions of future research. They are as follows:

RQ 1. *How did the level of sustainable development in the EU–27 countries change in terms of building stable infrastructure, promoting sustainable industrialization and fostering innovation between 2015–2020 (SDG_9 index)?*

RQ 2. *What are the differences between old EU–14 and new EU–13 in the implementation of Goal 9 of Agenda 2030?*

RQ 3. *How are the economic, environmental, energy parameters and the level of digitalization of the economies of the EU–27 countries related to the implementation of Goal 9 of Agenda 2030?*

To answer these questions, research was conducted using data from the Eurostat database and applying a range of analytical methods and tools. An assessment of the level of the EU countries in terms of building stable infrastructure, promoting sustainable industrialization and fostering innovation was carried out using a MCDM methods. The TOPSIS, WASPAS and EDAS methods were used for this part of the study. The Entropy, CRITIC and standard deviation (SD) methods were used to determine weights of the indicators used to assess the level of innovation, sustainable industrialization and infrastructure (by means of MCDM methods). On the other hand, two non-parametric tests were used to assess the relationship between the sustainability index in terms of building stable infrastructure, promoting sustainable industrialization and fostering innovation (determined with the MCDM methods), and the basic economic, environmental and energy parameters of each country's economy, based on which the Spearman's Rank-Order Correlation and Kendall rank correlation coefficient were determined.

The broad scope of the study, the inclusion of many diagnostic variables and the analytical tools used make it a novel and original approach to the presented subject. The main achievement of the study was the determination of sustainable development index for the EU countries (SDG_9), on the basis of which they were evaluated in the areas of innovation, infrastructure and sustainable industry. The basis for this part of the study was 14 selected indicators characterizing the areas of Goal 9 of Agenda 2030 between 2015–2020.

When compared to the existing research, the presented study is characterized by a new and original approach to the studied issue, as evidenced by a number of factors. The first of these concerns the object of research, which is the group of EU–27 countries. Due to their strong political, economic and social diversity and ambitious plans for sustainable development, these countries are extremely interesting objects of research. Particularly relevant in this regard is the inclusion of "old" EU countries (EU–14), which became members before 2004 (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, the Netherlands, Ireland, Luxembourg, Portugal, Spain, Sweden) and "new" EU countries (EU–13) accepted after 2004 (the Czech Republic, Poland, Romania, Slovakia, Slovenia, Bulgaria, Estonia, Latvia, Lithuania, Hungary and Croatia, Cyprus, Malta). The EU-13 countries (with the exception of Malta and Cyprus) have had long processes of transition from centrally planned to free market economy systems, which affects their current level of economic development. That is why, a comparison of the degree of sustainable development in these groups of countries should provide a number of lessons as well as point to potential courses of action for the EU as a whole to achieve the goals in question (consistent with Agenda 2030) by all EU members. The second factor attesting to the originality of the study is the selection of a set of 14 indicators characterizing the areas included in Goal 9 of Agenda 2030 in each country. The broad scope covered by these indicators lends credibility to the assessment carried out and provides an opportunity for a detailed analysis of the areas studied, as well as a discussion of the effectiveness of the economic policy pursued and the directions of its further development. Another factor testifying to the originality of the study concerns the approach based on Multi-Criteria Decision-Making (MCDM) methods. This applies to both the determination of weights of the indicators adopted for the study and the determination of the level of the EU countries in terms of innovation, sustainable industry and infrastructure (SDG_9 index). The use of such an approach increases the scientific value of the research and gives credibility to the results. Another important factor proving the originality of the study involves also determining the relationship between the Sustainable Development Index (SDG_9), a measure of achieving Goal 9 of Agenda 2030, and the basic economic, energy and environmental parameters of the EU–27 countries, including the DESI Digitization Index. Such an approach has not been presented so far, and undoubtedly can provide a lot of interesting information regarding the determined relationships and the interaction of studied factors.

Therefore, it can be assumed that the research topic undertaken is up to date and crucial from the point of view of both EU countries and other countries and regions that are planning to introduce a sustainable development economy. The challenge the EU has taken on, namely to build a sustainable environmentally neutral economy by 2050, involves huge investments in innovative and sustainable industry and energy, as well as efforts to win public favor for these changes. The positive conclusion of this process (in a sense as an experiment) will set an example that it is possible to run a competitive and efficient economy without harming the environment and taking care of future generations.

The structure of the study includes an introduction and justification of the purpose of taking up the topic of the paper (section 1) and a review of the literature in this field, which is presented in section 2. In turn, section 3 presents research methodology, analytical methods, and data used for the study. The next section of the paper (section 4) presents the results of the analyses, followed by a discussion of the results. The "Conclusions" section sums up the research and provides limitations and directions for possible future work.

Literature review

The concept of sustainable development was introduced in 1987 in the UN report "Our common future" (Brundtland, 1987). Nearly 30 years later, in 2015, the United Nations General Assembly adopted a resolution setting out the goals for the world's equitable and balanced development by 2030 (United Nations, 2015), which is a follow-up to the Millennium Declaration of 2000 (United Nations, 2000). The goals indicated in this document are closely intertwined, interpenetrating and complementing each other. This causes the 2030 Agenda, combining the most important areas of go-economic, social and environmental life, to represent a comprehensive approach to the development of civilization by 2030. An important aspect contained in Agenda 2030 is also the issue of world peace, which, especially in the current geopolitical situation in Europe, becomes even more important.

One of the Agenda's goals (out of 17) is Goal 9 "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation." Its great importance is primarily due to the fact that its implementation significantly affects the possibility of achieving the other Sustainable Development Goals. This is because economic inclusiveness and sustainable industrial development are the primary sources of income generation, and thus contribute to raising the standard of living of citizens. For these processes to be feasible, it is necessary to build an innovative knowledge-based economy that is environmentally friendly. The 9th goal of the Agenda 2030 in relation to sustainable development treats these three areas as a foundation, enabling the achievement of the other goals necessary for the development of the world (Bogers *et al*., 2022). Important elements of these are increased productivity and income, improved quality of life, improved health care and better and more accessible education, which of course also depends on the infrastructure in place (Vinuesa *et al*., 2020). It is also obvious that the sustainable use of new technologies supports the development of a knowledge-based society. It also creates correct conditions for innovative activity, the effects of which contribute to the improvement of living conditions related to such areas as medicine (Ciani *et al*., 2016), transportation (Cirella *et al*., 2019), manufacturing or energy use (Liu *et al*., 2018). Thus, it can be seen that without new technologies and innovations, it is difficult to pursue effectively the process of industrialization, and thus also to ensure an adequate pace of economic and social development.

Thus, it can be assumed that innovation, industrialization and infrastructure development (issues included in Goal 9 of Agenda 2030) are closely intertwined and play an important role in building sustainable economic prosperity for societies around the world. They are therefore a fundament for ensuring sustainable and peaceful development of the world.

Innovation, industrial modernization and sustainable development have been the subject of research for many years. In particular, this research is concerned with technological development, which has long been considered a tool for social transformation, especially when the economy is undergoing a technological transformation (Schumpeter, 1934).

Nowadays, industrial development, its modernization as well as sustainable development are considered solutions to ensure the dynamic development of society as a whole (Gomes *et al.,* 2022; Verdugo & Wright, 2020). Therefore, it can be said that technological innovation, science, investment in infrastructure are the basis for achieving sustainable industrial development.

The subject of the impact of innovation and industry on sustainable development is relatively new in the area of scientific interest and has developed intensively only in the last several years. Studies in this area include engineering, energy, economics, entrepreneurship, and policy and its impact on this development. In particular, they deal with the social impact of technology, the development of information and communications technology (ICT) and its impact on sustainable growth, education and e-learning, globalization and foresight technology, entrepreneurship and social technology, as well as RES-related technologies (Omri, 2020).

Among the many publications, it is worth mentioning a study by Bekhet and Latif (2018), who analyzed the impact of the quality of institutions and technological innovation on the pursuit of sustainable development in Malaysia. Based on it, they concluded that the interaction between governance and technological innovation contributes positively to the country's sustainable growth. Omri (2018), on the other hand, concludes that technological innovation in high-income countries contributes to environmentally friendly production and encourages investors to use innovative solutions for the environment. He also points out that low- and middle-income economies need to put more effort into the production and use of innovative technologies in order to achieve a balance between environmental protection and economic growth, since this balance is considered a public good. Kardos (2012), based on his research in the developed and developing EU countries, concludes that sustainable entrepreneurship, seen through the lens of innovative SMEs, fits into a system that supports sustainable development. This is because entrepreneurship is increasingly recognized as a driver of innovation and competitiveness and is key to achieving sustainable development.

Today, technological innovation underpins the process of digital transformation of the economy and enterprises towards the fourth industrial revolution (Małkowska *et al.*, 2021; Sabatini *et al.*, 2022; Tutak & Brodny, 2022; Valaskova *et al.*, 2022) and supports sustainable development (Berawi, 2019). The digital transformation of enterprises and the implementation of innovative technologies in them enable, among other things, the optimization of production processes and better use of energy and material resources at the industrial level (Modgil, 2020). Bonilla *et al*. (2018) and Oláh *et al*. (2020) argue that Industry 4.0 helps reduce energy and material flows in industrial environments. This happens mainly through the implementation of IIoT, CPPS, DDA, BD, AM and new business models based on new technologies and frameworks (Panetto *et al*., 2019).

In addition to innovation, an important aspect of pursuing sustainable development is adequate infrastructure. This is because infrastructure systems are the backbone of society, providing basic services such as water supply, energy, waste management, transportation, telecommunications, and many others (Miłek, 2022). Infrastructure development is designed to aid economic growth processes, reduce climate risks and improve Sustainable Development Goals (SDGs) indicators, as well reduce poverty and develop sustainable consumption. Thacker *et al*. (2019) indicate that infrastructure can either directly or indirectly influence the achievement of the SDGs, at the level of 72%. This is because the development of digital infrastructure helps implement modern digital technologies that can provide lean and safer production systems, further contributing to overall urban sustainability (Luthra *et al*., 2020). Recently, the topic of the impact of transportation infrastructure has also been a hot research issue in the context of the SDGs (Cohen, 2010; Correia *et al*., 2016; Heilig & Voss, 2015). Transportation infrastructure is a key component of economic development at all income levels, promoting personal well-being and economic growth (Cigu *et al*., 2019). From a sustainable development perspective, this infrastructure is a type of large-scale public work that has an import impact on countries' politics, economy, society, science, technology development, environmental protection, public health, and national security. Also, Prus and Sikora (2021) point out the important role of transportation infrastructure, which is a factor that guarantees economic growth and development due to the functions it performs (movement of people and goods). They point out that transportation accessibility facilitates the operation of local businesses, facilitating transportation related to obtaining materials needed to produce goods or provide services, and facilitates the lives of residents, who can move quickly and meet daily needs. This is especially important in rural regions, as Bacior and Prus (2018) also confirm. Achour and Belloumi (2016) also emphasize that transportation infrastructure is a motivator of economic growth and social welfare by improving production efficiency and investment performance for the private sector.

When referring to infrastructure, it is also vital to mention its telecommunications part. In this area, its importance for sustainable development is very high, especially regarding sustainable and resilient infrastructure that integrates environmental, social and governance aspects (Bocchini *et al*., 2014).

The studies cited, due to the thematic breadth directly and indirectly related to Goal 9 of Agenda 2030, can to a limited extent testify to the great importance of innovation, industry and infrastructure in achieving sustainable development of the economies of countries and regions of the world. On the other hand, with regard to assessing different groups of countries in terms of sustainable development, e.g., their innovation, different approaches have been used so far. Szopik-Depczyńska *et al.* (2018) developed a metric for assessing innovation within the framework of sustainable development policies of EU countries based on the Weber median. For this assessment, they used a set of 6 indicators that characterize the innovation process. However, they did not conduct a comparative analysis with MCDM or other linear ordering methods. Aytekin *et al*. (2022), on the other hand, examined and compared global innovation efficiency, which can be considered a key economic factor for the European Union member and candidate states, using the Global Innovation Index (GII) and compared it with the results obtained using the DEA and Efficiency Analysis Technique with Input and Output Satisficing (EATWIOS) method. This is a very interesting work, especially because of the research approach used to measure innovation, which, however, is characterized by a high degree of complexity. On the other hand, Kuzior *et al*. (2022) assessed the parameters of the national innovation ecosystems of EU member states with different innovation potentials and Ukraine, from the point of view of their impact on the innovative development of the countries of the world.

MCDM methods, which belong to decision support methods in multi-criteria problems, are very often used to evaluate other sustainability issues. In this area, this mainly concerns energy (Bartolini *et al*., 2017; Ziemba, 2022) and climate (Fura *et al.,* 2017; Siksnelyte-Butkiene *et al*., 2022) issues. For these analyses, however, authors most often use only one research method, which limits the possibility of comparing results with those from other methods. This is because, as the literature (Brodny & Tutak, 2021; Mulliner *et al.,* 2016) indicates, the choice of method for multi-criteria studies, due to different criteria aggregation techniques, affects the results.

Taking into account the fact that the assessment of the level of sustainable development related to Goal 9 of Agenda 2030 is a multi-criteria problem, an approach based on MCDM methods was used to solve it. On the other hand, the use of more than one method for the analysis provides the possibility of obtaining a more reliable result, taking into account the different approaches to the analysis of the studied problem itself. In the case presented here, the averaging of results obtained by different methods was used, which gives the opportunity to consider different analytical techniques that can be used to solve this problem.

Therefore, it can be assumed that the undertaking of the research topic, the results of which are presented in the paper, is fully justified and is part of a very topical and important problem of the modern world. And the results obtained, due to the new approach to this topic should enrich the knowledge in this area and be used to implement this concept even more effectively.

Research methods

The analysis and assessment of the EU countries in terms of implementing Goal 9 of Agenda 2030 for sustainable development was carried out based on data from the Eurostat (2015–2020) database for the years 2015–2020. The choice of the range of years studied was due to the fact that the base year of this Agenda is 2015, and the latest available data is for 2020.

The significance of the subject matter undertaken, for the current and future economic and social development of the countries studied and the EU as a whole, make it necessary to approach this research in the broadest possible scope. Therefore, the research included a set of 14 indicators characterizing all three areas (Infrastructure, Industry and Innovation) contained in Goal 9 of Agenda 2030. A summary of the indicators considered in the study, along with their designations, is shown in Table 1.

When referring to the indicators included in the study, it is worth highlighting the importance of those characterizing research and development (R&D) activities (I1; I2; I3 and I4). Their inclusion is intended to show how individual countries approach the problem of innovating their economies through expenditures on this activity. Interest in this area of investment is motivated by their great importance in generating innovative solutions that have a multidimensional positive impact on sustainable development. Innovation drives economic growth, increases employment and income growth, contributes to the quality of life and competitiveness of products and the operation of businesses. The intensity and magnitude of R&D expenditures significantly affect the increase in profitability of enterprises, which, when engaging in R&D, experience higher productivity growth than non-innovators (Medda & Piga, 2014; Tsegaye, 2023). The group of indicators related to R&D expenditures is the financial component of the analysis, since the stream of funds allocated for these purposes is treated as the foundation of innovation development in any country.

The increase in innovation in each country as a result of R&D expenditures is also linked to human capital. This refers to people employed in scientific and research units and in the high-tech and service sectors using acquired knowledge and skills in this area. These people are directly related to the processes of finding new solutions and implementing them. Human capital is a key factor in economic growth and development, so it is important that active state and regional policies support this development. Therefore, the study additionally included indicators related to the percentage of people with higher education (I8) and graduating from technical colleges in a given calendar year (I9), as well as an indicator characterizing the digital skills of people aged 55–74 due to their risk of digital exclusion (I13). This is due to the fact that one of the tasks related to the implementation of Goal 9 of Agenda 2030 is to increase access to information and communication technologies.

An important indicator of a country's innovativeness is also an indicator of effects, i.e., the number of patent applications filed with the European Patent Office (EPO)–I7. It is debatable to take this indicator as a measure of innovation since many inventions may not be referred to patent offices or the procedures involved in filing new solutions. Despite this shortcoming, in combination with the other indicators, it completes the picture and evaluation of the level of innovation of countries.

The last group of indicators characterizes transportation infrastructure (I10 and I11). Their task is to monitor progress in building resilient infrastructure for social and sustainable industrialization. These indicators are part of the task of Goal 9 of Agenda 2030: "Develop reliable, sustainable and resilient infrastructure of good quality, including regional and cross-border infrastructure that supports economic development and human well-being."

Table 2 shows the values of descriptive characteristics of the adopted indicators, which confirm their high variation among the studied EU–27 countries (treated as diagnostic variables).

The study used a MCDM methods for determining indicator weights and ranking (selecting the best alternative). The Entropy, CRITIC and SD methods were used to determine weights of the indicators adopted for the study, and the EDAS, WASPAS and TOPSIS methods were used to create a ranking of the EU–27 countries.

The purpose of using a MCDM methods approach based on the Entropy-CRITIC-SD and EDAS–WASPAS–TOPSIS methods was to determine as reliably as possible the sustainable development index (SDG_9) and the ranking of the EU–27 countries with regard to the achievement of Goal 9 of Agenda 2030 (i.e., "building stable infrastructure, promoting sustainable industrialization and supporting innovation").

The research also checked for correlations between the determined, for each EU–27 country, value of the Sustainable Development Index (SDG_9) and the basic economic, environmental and energy parameters, as well as the degree of digitization of these countries in the analyzed period between 2015-2020 (GDP per capita, and gross domestic expenditure on R&D as % of GDP, DESI digitization index, energy productivity, greenhouse gas emissions).

The course of the ongoing research procedure is shown in Figure 1.

When conducting studies with multiple variables treated as criteria for the evaluated options (EU countries), there is a high complexity in the process. In addition, there is a need to objectively assign weights to the evaluation indicators (criteria). Therefore, to assess the level of EU countries in terms of sustainable development, a MCDM methods approach based on 6 independent methods was proposed. Three methods were used to determine weights of indicators (assessment criteria): Entropy, CRITIC and Standard Deviation (SD). The EDAS, WASPAS and TOPSIS methods were used to essentially determine the value of the sustainable development index (SDG_9). The research procedure using Entropy, CRITIC, SD and EDAS, WASPAS and TOPSIS methods is shown in Figure 2.

The following sections present research methods used in the study.

The Shannon-Entropy method

Entropy is defined as a measure of disorder (Hwang & Yoon, 1981). The relative measure of entropy is determined by the following equation:

$$H(X) = \frac{\bar{H}(X)}{ln(n)} = -\left(ln(n)\right)^{-1} \sum_{i=1}^{n} p_i ln(p_i) = -h_0 \sum_{i=1}^{n} p_i ln(p_i) \quad (1)$$

The procedure for determining weights of individual indicators, according to this method, is as follows:

– To construct a decision matrix:

$$X = \left[x_{ij}\right]_{m \times n} \quad (2)$$

where: x_{ij} is the performance rating of the alternative i on the criterion j, m is the number of the alternatives and n is the number of the criteria assessment.

– To normalize the decision matrix:

$$x_{ij}^{*} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (3)$$

– To determine Entropy:

$$E_j = -h_0 \sum_{t=1}^{m} x_{ij}^{*} \, ln\left(x_{ij}^{*}\right) \quad (4)$$

where h_0 is a positive constant equal to $(lnM)^{-1}$

– To determine the level of Entropy variation for each evaluation criterion:

$$d_j = 1 - E_j \quad (5)$$

– To determine objective weights (w_{ij}) of evaluation criteria based on the Shannon's concept of entropy:

$$w_{ij} = \frac{d_j}{\sum_{j=1}^{n} d_j} \quad (6)$$

The CRITIC method

CRiteria Importance Through Intercriteria Correlation – CRITIC method is a correlation method (Diakoulaki *et al*., 1995). The stages of determining indicator weights in this method are as follows:

– To construct a decision matrix (equation 2).
– To normalize the decision matrix in accordance with equation (7):

$$x_{ij}^{*} = \frac{X_{ij} - min\left(X_{ij,} i=1,2,\ldots,m\right)}{max\left(X_{ij,} i=1,2,\ldots,m\right) - min\left(X_{ij,} i=1,2,\ldots,m\right)} \quad (7)$$

$for\ i = 1, 2 \ldots, m\ and\ j = 1, 2 \ldots, n$

– To determine the standard deviation (SD) for the evaluation criteria in the normalized decision matrix:

$$SD = \sqrt{\frac{\sum_{i=1}^{m}(x_i - \bar{x})}{m-1}} \quad (8)$$

– To determine correlation coefficients (r_{jk}) between the evaluation criteria of the normalized decision matrix:

$$r_{jk} = \frac{\sum_{i=1}^{n}(x_{ij}-\bar{x}_j)(x_{ik}-\bar{x}_k)}{\sqrt{\sum_{i=1}^{n}(x_{ij}-\bar{x}_j)^2 \sum_{i=1}^{n}(x_{ik}-\bar{x}_k)^2}} \quad (9)$$

– To determine attribute weights:

$$w_{ij} = \frac{C_j}{\sum_{i=1}^{n} C_j} \quad (10)$$

where:

$$C_j = SD \sum_{i=1}^{n}\left(1 - r_{jk}\right) \quad (11)$$

where*:* C_j is the quantity of information contained in *j*-th criterion*, SD* is the standard deviation of the *j*-th criterion and r_{jk} is the correlation coefficient between *j*-th and *k*-th criteria. For a criterion the high standard deviation and low correlation with the other criteria mean that given criterion weight is high. The higher value of C_j implies a greater amount of information that is obtained from a given criterion

Standard deviation (SD) method

The procedure for determining weights using the standard deviation (SD) method includes the following steps:

– To construct a decision matrix (equation 2);
– To normalize the decision matrix (equation 7);
– To determine the standard deviation for the evaluation criteria in the normalized decision matrix (equation 8)'
– To determine weights of the evaluation criteria according to equation (12):

$$w_{ij} = \frac{x_i}{\sum_{i=1}^{n}\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i-\bar{x})^2}} \quad (12)$$

The Evaluation Based on Distance from Average Solution method

The Evaluation Based on Distance from Average Solution (EDAS) method is based on aggregate values obtained as positive distances from the mean and values obtained as negative distance from the mean (Keshavarz Ghorabaee *et al.*, 2015). This means that the EDAS method relies on the intermediate scenario becoming the reference variant of the evaluation. The algorithm for solving a decision problem with a number of m alternatives and a number of m criteria in the EDAS method consists of the following steps:

– To construct a decision matrix (equation 2).
– To determine the average solution for all criteria:

$$AV = \left[AV_j\right]_{1\times n} \tag{13}$$

$$AV_j = \frac{\sum_{i=1}^{m} x_{ij}}{m} \tag{14}$$

– To calculate for each alternative a matrix of PDA (positive distance from the average solution) and NDA (negative distance):

$$PDA = \left[PDA_{ij}\right]_{m\times n} \tag{15}$$

$$NDA = \left[NDA_{ij}\right]_{m\times n} \tag{16}$$

where for stimulants:

$$PDA_{ij} = \frac{max\left(0,(x_{ij}-AV_j)\right)}{AV_j} \tag{17}$$

$$NDA_{ij} = \frac{max\left(0,(AV_j-x_{ij})\right)}{AV_j} \tag{18}$$

And for destimulants:

$$PDA_{ij} = \frac{max\left(0,(AV_j-x_{ij})\right)}{AV_j} \tag{19}$$

– To determine weighted sums of PDA and NDA for each alternative:

$$SP_i = \sum_{j=1}^{n} w_j PDA_{ij} \tag{21}$$

$$SN_i = \sum_{j=1}^{n} w_j NDA_{ij} \tag{22}$$

where: w_j is a weight of *j*-th criterium

– To normalize SP and SN values, according to equations 23 and 24:

$$NSP_i = \frac{SP_i}{max_i(SP_i)} \tag{23}$$

$$NSN_i = 1 - \frac{SN_i}{max_i(SN_i)} \tag{24}$$

– To determine the Appraisal Score (AS_i) index for each alternative:

$$AS_i = \frac{1}{2}(NSP_i + NSN_i), 0 \leq AS_i \leq 1 \tag{25}$$

– To rank the AS_i values in descending order. The alternative with the largest AS_i value is the best.

The result of the EDAS method is therefore the determined AS_i index. For this method, the alternative with the largest value of this index is the best.

The Weighted Aggregated Sum Product Assessment method

The Weighted Aggregated Sum Product Assessment (WASPAS) method is a multi-criteria decision-making method. The general idea of this method is that a given MCDM problem is based on *m* alternatives and *n* decision criteria (Zavadskas *et al.*, 2012). Each criterion has a specific weight *wj*, a *xij*, which is the weighted value of alternative *i* when evaluated against criterion *j*.

The algorithm for this method is as follows:

– To construct a decision matrix (equation 2).
– To normalize the decision matrix:

For stimulants:

$$\overline{x_{ıȷ}} = \frac{x_{ij}}{maxx_{ij}} \tag{26}$$

For destimulants:

$$\overline{x_{ıȷ}} = \frac{minx_{ij}}{x_{ij}} \tag{27}$$

– To determine the total relative weight of the *i*-th alternative:

$$Q_i^{(1)} = \sum_{j=1}^{n} \overline{x_{ıȷ}} w_j \tag{8}$$

– To determine the total relative importance of the *i*-th alternative:

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(\overline{x_{ıȷ}}\right)^{w_j} \tag{29}$$

– To determine the total importance of alternatives, called the weighted aggregate product assessment method (WASPAS):

$$Q_j = \lambda \sum_{j=1}^{n} \overline{x_{ıȷ}} w_j + (1 - \lambda) \sum_{j=1}^{n} \left(\overline{x_{ıȷ}}\right)^{w_j}, \lambda = 0, \ldots\ldots 1. \tag{30}$$

The analyses assumed the value of $\lambda = 0.5$.

The result of the WASPAS method is a determined O_j index taking values in the range [0, 1]. The alternative with the largest value of this indicator is the best.

The Technique for Order of Preference by Similarity to Ideal Solution method

In the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method, the decision options under consideration are compared with abstract weighted reference solutions: ideal and anti-ideal. The method uses a measure of relative distance to the best solution, which is the pattern (ideal), and a measure to the worst solution, which is the anti-pattern (anti-ideal). Finally, a TOPSIS synthetic measure is determined for each alternative (Hwang & Yoon, 1981).

The algorithm for the TOPSIS method is as follows:

- To construct a decision matrix (equation 2).
- To normalize the decision matrix:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}} \tag{31}$$

- To determine weighted normalized decision matrix:

$$x_{ij}^{*} = x_{ij} \times w_{ij} \tag{31}$$

- To identify the ideal $S^{+}$and anti-ideal solution S^{-}:

$$S^{+} = (x_1^{+}, x_2^{+}, x_3^{+}, \dots . x_n^{+}\ ) = \{(max_i x_{ij}|j \in B|), (min_i, x_{ij}|j \in C|)\} \tag{32}$$

$$S^{-} = (x_1^{-}, x_2^{-}, x_3^{-}, \dots . x_n^{-}\ ) = \{(min_i x_{ij}|j \in B|), (max_i, x_{ij}|j \in C|)\} \tag{33}$$

- To determine the Euclidean distance of the object from the ideal S^{+} and anti-ideal S^{-} variant:

$$d_i^{+} = \sqrt{\sum_{j=1}^{n} \left(x_{ij} - x_j^{+}\right)^2} \tag{34}$$

$$d_i^{-} = \sqrt{\sum_{j=1}^{n} \left(x_{ij} - x_j^{-}\right)^2} \tag{35}$$

- To determine the coefficient of relative proximity of decision variants S_i to the ideal solution S^{+} (35):

$$P_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \tag{36}$$

The result of the TOPSIS method is the determined P_i index, which takes values in the range [0, 1]. The best alternative is the index with the largest value.

In each MCDM method, an evaluation index (index, coefficient) is determined for alternatives, based on which they can be ranked. In the present study, the final value of the evaluation index of EU countries was determined based on the subindices obtained from the EDAS, TOPSIS and

WASPAS methods. Since the values of these indices are not comparable, they were brought to a comparable form using the zero-unitization equation:

– if a higher value of the evaluation index is better in a given MCDM-type method (stimulant):

$$R_i(AS_i or\ Q_j\ or\ P_i) = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}} \quad (37)$$

– if a lower value of the evaluation index is better in a given MCDM-type method (destimulant):

$$R_i(AS_i\ or\ Q_j or\ P_i) = \frac{max\ x_{ij} - x_{ij}}{maxx_{ij} - minx_{ij}} \quad (38)$$

In the analyses presented in the paper, only equation 37 was used, since all the determined evaluation indices are stimulants. Equation 38, on the other hand, should be used with destimulants.

According to this method, the final ranking positions were determined by the value of the aggregate index determined by individual component methods of MCDM. This index should be regarded as a measure of the achievement of Goal 9 of Agenda 2030, and it was determined from the following equation (39):

$$SDG_9 = \frac{1}{v}\sum_{p=1}^{v} R_i \quad (39)$$

where: SDG_9 is the index of the aggregate value of indices from each component method of the MCDM, R_i is the value of the index in the i-th method, v is the number of methods.

Based on the determined values of the SDG_9 index, an assessment of the EU countries was made in terms of supporting innovation, building stable infrastructure and promoting sustainable industrialization. Based on the determined average values of the relevant indices and the standard deviation from the values of these indices for each method used, the level classes were determined in terms of the implementation of Goal 9 of Agenda 2030 of the EU–27 countries. This is because none of the methods included in the study allows determining this level independently:

Class 1 High level

$$SDG_9 \geq \overline{SDG_9} + s_{SDG_9} \tag{40}$$

Class 2 Average level

$$\overline{SDG_9} + s_{SDG_9} > SDG_9 \geq \overline{SDG_9} \tag{41}$$

Class 3 Moderate level

$$\overline{SDG_9} > SDG_9 \geq \overline{SDG_9} - s_{SDG_9} \tag{42}$$

Class 4 Low level

$$SDG_9 < \overline{SDG_9} - s_{SDG_9} \tag{43}$$

where: SDG_9 are the indicators for the achievement of Goal 9 of Agenda 2030 for the EU country, $\overline{SDG_9}$ is the average value of the indicator for the EU–27 countries, s_{SDG_9} is the standard deviation from the average value of the indicator for the EU–27 countries.

In the final stage of the research, analyses were conducted to determine whether the implementation of Goal 9 of Agenda 2030 is related to selected economic, energy, environmental and cyberspace parameters in the countries studied. Two non-parametric tests in the form of Spearman's Rank-Order Correlation and Kendall rank correlation coefficient were used for this part of the study.

The Spearman's Rank-Order Correlation makes it possible determine the consistency of the ordering of the values of two characteristics. The ranking of traits is in the ascending or descending direction (the ordering direction of the two traits must be the same).

The Kendall rank correlation coefficient, on the other hand, is based on the difference between the probability that two variables are arranged in the same order (for the observed data) and the probability that their ordering differs. It takes values between "-1" and "+1". The Kendall rank correlation coefficient indicates the strength and direction of the relationship.

Results

Analysis of the dynamics of change in the values of indicators characterizing sustainable development in the EU countries

In order to determine changes that have occurred in the values of indicators characterizing sustainable development (related to the implementation of Goal 9 of Agenda 2030) in the EU countries between 2015–2020, the values of indices for the dynamics of change were determined (Table 3). The values of these indices show the magnitude and direction of changes in the indicators included in the study.

When analyzing the values of the determined indices in individual EU countries (Table 3), one can see a large variation in them during the period under study. When referring only to the index of total intramural R&D expenditure by business enterprise sector (calculated per capita), the largest increase in this expenditure was reported in Cyprus (an increase of more than 290%), and a decrease in Luxembourg (-2%). Countries with large increases in this indicator included also Poland and Greece. When analyzing the increase in R&D outlays by business enterprise sector, it can be noted that in the so-called "new EU–13" countries, the increase was 87% on average, while in the so-called "old EU–14" countries, it was "only" 30%. It should also be remembered that the countries of the "old EU–14" have been characterized by a much higher level of outlays on R&D activities for years, so the dynamics of this growth is somewhat smaller than in the countries of the new EU–13, whose outlays are still at a low level. However, in absolute terms, these outlays in the "old EU–14" countries are much higher. R&D activity has also been included in the overarching goals of the "Europe 2020" strategy, which emphasizes its role as one of the pillars of the development of a sustainable economy based on knowledge and innovation.

Assessment of the level of sustainable development in the EU countries in terms of achieving Goal 9 of Agenda 2030

Using a MCDM methods, an assessment was carried out and a ranking of EU countries was created in terms of the implementation of Goal 9 of Agenda 2030 for sustainable development between 2015–2020. All indicators adopted for the study were stimulants.

In accordance with the research procedure presented in Section 3, in the first stage of the analysis, weights for each indicator were determined. These values were determined using the Entropy, CRITIC, SD, and finally the Average Entropy-CRITIC-SD method. The results obtained for 2015 and 2020 are shown in Figure 3.

The results of the calculations show that the values of weights of the indicators included in the study vary significantly, depending on the method used (Figure 3). These differences show that it is necessary to use more than one analytical method to avoid giving too much or too little weight assigned to a particular indicator. This is because a large spread of values, depending on the method adopted for determining the weights of indicators, can lead to a change in the ranking of countries. Therefore, it is reasonable to use a more universal method, which at the same time would consider different approaches for their determination. Therefore, the mean-weight method was used for the final determination of indicator weights. In this method, the final value of the indicator weight is determined as an average value from the Shanon-Entropy, CRITIC and SD methods.

The determined values of the weights of the indicators accepted for calculation are shown in Figure 4. The highest weight over the entire period considered in the study was determined for the indicator of patent applications to the European Patent Office (I7), and the lowest — for the indicator of level of internet access (I12). This is due to the fact that these indicators have the highest (I7) and lowest (I12) levels of variation among the studied set of countries.

In the next stage, it was checked how the values of the weights for the indicators included in the study changed between 2015–2020. For this purpose, coefficients of variation were determined for them. The results are presented in Table 4. The calculations showed that the largest variation between 2015–2020 was observed for the weights of the indicators; employment in high- and medium-high technology manufacturing sectors (I5), tertiary educational attainment (I8) and science and technology graduates (I9), for which the value of the coefficient of variation was 6% (for the period 2017/2018). The highest dynamics of change, year-on-year, was noted for the weight of the index of patent applications to the European Patent Office (I7), in 2017/2016 — when its value changed by +12%.

Based on the determined weights for each indicator, the next step was to determine values for the sustainability indices specific to each method used (i.e., the A_{si} index in the EDAS method, the Q_i index in the WASPAS method and the P_i index in the TOPSIS method). On their basis, the ranking of the EU–27 countries in terms of sustainable development (adequate for the achievement of Goal 9 of Agenda 2030) was created. The results of the calculations for one sample year (2015), along with the ranking position of each country, are presented in Table 5.

The results show that, depending on the method used, the ranking positions vary from country to country. In 2015, this was true for as many as 24 of the 27 EU countries. Therefore, in order to obtain unambiguous results, taking into account the sub-scores obtained from all these methods, the "Mean-index rank" method was utilized. Due to its wide and frequent application in such cases, this method seems the most appropriate for the process under study (Liao *et al*., 2011). According to this method, the final ranking positions were determined by the value of the aggregate index determined by individual component methods of MCDM. This index should be regarded as a measure of the achievement of Goal 9 of Agenda 2030, and it was determined from the equation (39).

The positions of individual EU countries in the ranking, determined by the value of the SDG_9 index, for the period between 2015–2020, by applying the "Mean-index rank" method are shown in Table 6. In turn, Figure 5 summarizes the averaged values of the SDG_9 index for the entire 2015–2020 period and the ranking positions determined based on it for each EU country studied.

The results show that in terms of the sustainability of EU countries with regard to supporting innovation, building stable infrastructure and promoting sustainable industrialization, Luxembourg, the Netherlands, Denmark, Sweden and Germany achieved the best results between 2015–2020, while Bulgaria and Greece achieved the worst results. Over the period under review, Bulgaria and Greece did not improve their final ranking positions.

A comparison of the values of the SDG_9 index in 2015 and 2020 shows what changes have occurred in each country. The greatest progress in achieving Goal 9 of Agenda 2030 between the year 2015 and the year 2020 was made by Cyprus (up from 21st to 13th place), Germany (up from 5th to 1st place), Spain (up by 6 positions), Romania (up by 3 positions), Belgium and Slovenia (up by 2 positions). At the same time, some countries, lowered their rankings compared to the base year — these are the Czech Republic, Ireland, France, Lithuania, Croatia. Slovakia and Estonia recorded the largest decline, by 6 and 5 positions, respectively.

Luxembourg, being the 2015–2019 ranking leader, is counted among the most innovative, and thus the most developed and competitive countries in the world. Mindful of the constant changes and emerging socio-economic challenges, the country is implementing various types of initiatives aimed at strengthening the innovative capacity of domestic economic players, as well as links and cooperation between public research institutions and universities (Peroni & Ferreira, 2012). The country has one of the highest levels of concentration of public and private research institutions in Europe. Worth mentioning is the fact that the scientific sphere in Luxembourg is "driven" by young employees, who have enormous potential for development.

Germany's high position, on the other hand, and promotion to 1st place in 2020, is mainly due to the fact that in recent years the country has been rapidly developing an innovative R&D environment (Kynčlová *et al*., 2020). The innovation of the German economy is also confirmed by the large number of patent applications. In 2020, the European Patent Office approved 20,056 German patent applications — more than twice as many as applications from France, for example. Germany also leads Europe in terms of "triadic" patent applications, that is, a series of relevant patents filed with the European Patent Office (EPO), the United States Patent and Trademark Office (USPTO) and the Japanese Patent Office (JPO). Germany is also home to the largest scientific community in Europe, with nearly 24% of EU scientists living and working there. Germany is shaping a de facto knowledge society, so a course has been taken to meet the challenges that arise from intense global competition for innovation (Sanders *et al*., 2020).

Based on the determined values of the SDG_9 index, an assessment of the EU countries was made in terms of supporting innovation, building stable infrastructure and promoting sustainable industrialization. Based on the determined average values of the relevant indices and the standard deviation from the values of these indices for each method used, the level classes were determined in terms of the implementation of Goal 9 of Agenda 2030 of the EU–27 countries.

Based on the calculations (eq. 40–43), the classes of the level of sustainable development of each country were established. Table 7 show the groups of similar countries in terms of the level of sustainable development.

When analyzing the results (Table 7), it can be concluded that throughout the analyzed period, Denmark, Germany, Luxembourg, the Netherlands, Sweden and Finland had the highest level of sustainability in supporting innovation, building stable infrastructure and promoting sustainable industrialization, while Bulgaria and Greece had the lowest level. In 2015, 2016 and 2017 and 2019, the low level of this development also occurred in Romania, between 2019–2020 in Portugal, and in 2018 and 2020 in Lithuania, and in 2017 and 2019 also in Croatia.

Throughout the analyzed period, Denmark, Germany, Luxembourg, the Netherlands, Sweden and Finland were characterized by a high level of sustainability, and Bulgaria and Greece by a low level. The largest number, as many as 15 countries, were characterized by a medium-low level (among them mainly countries belonging to the so-called "new EU–13"). The medium-high level was found for four countries included in the so-called "old EU–14": Belgium, Ireland, France, Austria.

The designated ranking clearly indicates that the countries included in the so-called "old EU–14" are characterized by high and medium-high levels of sustainable development throughout the analyzed period. The exceptions are Greece, characterized by a low level, and Spain, Italy and Portugal characterized by a medium-low level. It is worth noting that no country in the so-called "new EU–14" (which joined the community after 2004) reached the high level or at least the medium-high level considering the average level for the 2015–2020 period. It should be mentioned, however, that the assessment of the level of each EU country in terms of development related to innovation, industrialization and infrastructure was made in comparison with other member states for a specific calendar year. This causes that even with no improvement in the ranking, a country can show progress in the assessed areas. On the other hand, an improvement in ranking position is associated with achieving a higher level than the preceding countries, which in the case of highly developed countries is difficult due to their high initial values of the examined indicators.

In the next stage of the research, the Spearman's Rank-Order Correlation and the Kendall rank correlation coefficient for the entire European community were determined based on the determined average values of the SDG_9 index for the period 2015–2020 and the average values for this period of selected economic, environmental and energy parameters. The results of the calculations are shown in Table 8.

The results show a positive statistically significant relationship between the SDG_9 index and the values of GDP per capita, R&D expenditures (as % of GDP), energy productivity, DESI digitization index and GHG emissions per capita. By contrast, no such relationship was found between the SDG_9 index and total GHG emissions expressed in thousand tons. At the same time, the analysis showed that an increase in the SDG_9 index has a negative relationship with GHG emissions in relation to GDP values.

It is noteworthy that the determined values for the Kendall rank correlation coefficient show similar values with the Spearman rank correlation coefficients, but the strength of the relationship between the studied parameters was for the Spearman rank correlation coefficients significantly higher.

The results clearly indicate that sustainable development in terms of innovation, building stable infrastructure and promoting sustainable industrialization is closely related to the country's wealth, support for research activities and the digitization of the economy, which may now be crucial for achieving Goal 9 of the Agenda 2030 (SDGs).

Discussion

The pursuit of sustainable development is an extremely complex process, involving virtually all economic and social areas of individual countries and regions. Achieving success requires the involvement of all available forces and resources, as well as the close cooperation of all stakeholders in the implemented processes. In the European Union, the concept of sustainable development is a fundamental and overarching goal, which is included in Article 2 of the Lisbon Treaty (2007). This causes all EU–27 countries to be obliged to implement this strategy, as well as to cooperate in solidarity in order to achieve the set goals.

In the context of the assumptions and goals of sustainable development, the future must be based on innovative solutions, adequate infrastructure and the digitalization of the economy. The realization of these tasks will only be possible through the development of science, targeted investment in scientific research and building a knowledge-based economy and society. This will make it possible to compete effectively in global markets and maintain an acceptable social model for citizens, as well as taking into account the needs of the environment (Senise *et al*., 2021). Given the role and importance of these factors, the UN has included them in Goal 9 of Agenda 2030: "Industry, Innovation and Infrastructure." The EU has taken these goals very seriously, placing a strong emphasis on the tasks included in this Agenda. It broadly supports sustainable development, including building appropriate infrastructure, implementing new and innovative technologies, increasing access to information and communication technologies, and striving for affordable and universal access to the Internet (Vyas-Doorgapersad, 2022). All of these activities are also intended to promote social development and be environmentally neutral.

Since these processes involve all EU–27 countries, and at the same time are very important for the further development of the region's economy, it was reasonable to conduct a study to assess the state of sustainable development of these countries.

The results obtained showed that among the EU–27 countries, Denmark, Germany, Luxembourg, the Netherlands, Finland, Sweden achieved a high level of development in the analyzed period (2015–2020) in supporting innovation, building stable infrastructure and promoting sustainable industrialization. These countries can be described as leaders in the implementation of Goal 9 of Agenda 2030.

The second group of countries, which are characterized by an average level throughout the analyzed period, includes Belgium, Ireland, France and Austria. These countries can be described as followers of the leaders in the implementation of Goal 9 of Agenda 2030.

All of the countries in these two groups are counted among the most economically developed countries in the European Union, while at the same time they are counted among the so-called "old EU–14" countries, i.e., those that joined the community before 2004. As some studies (Pece *et al*., 2015; Pegkas *et al*., 2019; Pradhan *et al*., 2020) indicate, economically developed countries are characterized by the highest expenditures on R&D, and this in turn translates into innovation, infrastructure development and industrial development, which is also confirmed by the results obtained in this paper. Innovation, R&D expenditures and investment in technology are prerequisites for competitiveness and progress, and through them sustainable economic growth (Schot & Steinmueller, 2018). The high level of development of these countries, characterized by the value of the SDG_9 index, clearly indicates that educational inputs, technological innovation and infrastructure form a mechanism that is closely linked to economic growth, increased energy productivity, reduced greenhouse gas emissions and increased levels of digitization of the economy (Table 8).

The third group includes countries characterized by a medium level of development in terms of achieving Goal 9 of Agenda 2030. These countries include Czechia, Estonia, Spain, Croatia, Italy, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Romania, Slovenia, Slovakia. These are countries that can be described as having moderate development in supporting innovation, building stable infrastructure and promoting sustainable industrialization.

The last group is made up of countries with a low level of development of a sustainable economy, namely Bulgaria and Greece. The achievements of these countries in the realization of sustainable development are well below the EU–27 average. Among the countries of the so-called "old Union–14", the least innovative and industrialized is the economy of Greece. This is due to constant economic crises in this country, which undoubtedly affects the undertaking of innovative activities by Greek companies. Among the countries of the "new EU–13", Bulgaria has the most work to do, as it still faces many challenges related to industrialization and entrepreneurship, as well as the transition from a centrally planned economy to a free market economy (Hess, 2020).

It is very significant that the last two groups include all the countries included in the so-called "new EU–13," that is, countries that have only been members of the EU since 2004, and four countries included in the "old EU-14." This clearly shows that the countries of the "new EU–13" fare somewhat worse in key areas of their development related to innovation, infrastructure development or industrialization. This is mainly due to the delay in the introduction of the market economy, as well as lower wealth and high social resistance to the changes.

In general, processes related to technological development, innovation, infrastructure and industrial development in Western European and Scandinavian countries (EU–14) started earlier than in the EU–13, which meant that their level is now much higher. For many years, these countries have been supporting innovation activities, allocating huge expenditures on R&D activities, as well as on science and higher education, which is evident in various types of rankings, such as universities (Börje *et al.*, 2015).

It is therefore obvious that the countries of the new EU–13 need more time to catch up with this backlog, not always dependent on them. In this regard, it is necessary to support them and provide solidarity of the more developed countries. Also important is close cooperation between the countries, e.g., in the areas indicated in the analysis, coordination of EU assistance and implementation of joint projects. The use of good practices and joint implementation of key objectives of the EU's sustainable development policy should facilitate and accelerate the process of leveling off.

Without doubt, the basis for such activities should be innovation, infrastructure development and industrialization, and building a knowledge-based economy (Czyżewski *et al.*, 2021; Rasmus *et al*., 2021; Świadek *et al*., 2022). It is therefore necessary to continuously invest in research and development and support innovation, so as not to fall into the so-called middle development trap (Sakiewicz *et al*., 2022; Sonobe, 2019).

Developing countries, i.e., those in the medium-low and low sustainable development groups, need to dramatically increase science funding and R&D spending. The level of education of young people, which is close to the EU average, or the level of employment in knowledge-intensive service sectors and employment in high- and medium-high technology manufacturing sectors can be considered positive, in many countries of these groups, compared to countries counted among the EU "leaders."

When discussing the results obtained, it is also worth comparing them with the results for monitoring the sustainable development goals, i.e., the ranking created by the Sustainable Development Report (2015–2020) The detailed results of the comparison of the rankings obtained in this study and those published (Sustainable Development Report, 2015–2020) are shown in Table 9.

The analysis of the results indicates certain differences. However, it is positive that in many cases the differences between the analyzed rankings were not large, and the positions held by individual member states in both rankings were often similar. The noticeable difference is in the country leading in both rankings. In the present study, the leading positions were held as many as 5 times by Luxembourg (2015–2019) and once by Germany (2020). By contrast, in the ranking according to one report (Sustainable Development Report, 2015–2020), the leading position was held by Denmark (2015, 2016 and 2018) and Finland (2017, 2019–2020). The biggest differences were between countries such as Italy and the aforementioned Luxembourg, which was ranked 7th (2015–2016), 9th (2017–2018) and 10th (2019–2020) during the analyzed timeframe, while in the ranking of this publication, it is ranked first between 2015–2019 and second in 2020. The differences that occur are due to a different approach to the analysis and a different set of indicators used for the final evaluation.

All in all, the results of the consistency of the classification of the studied countries in both rankings can be assessed as good. The values of the correlation coefficients (Table 10) testify to a good match. The highest value of the correlation coefficient between the obtained rankings occurs for 2015, and the lowest — for 2020.

The discussion presented here covered only a small part of the results obtained. Their comprehensiveness makes it possible to refer to many parts of them included in the work, depending on the needs and issues considered. According to the authors, they provide very good opportunities for interpretation and analysis of the areas and sub-areas covered by the sustainable development of the EU–27 countries, as well as analysis of changes in the level of sustainable development in individual countries during the period under study.

Conclusions

Sustainable development is a multidimensional process that has now become the basis for the development of the economy of many countries and regions. This has been taken into account in its legislation by the UN adopting sustainable development as one of the basic directions of world development in Agenda 2030. This concept has been adopted for implementation by the EU–27 countries, becoming the basic direction of development of the European economy.

Of particular importance in this process is the implementation of Goal 9 of Agenda 2030, including the need to build stable infrastructure, promote sustainable industrialization and foster innovation. Taking these trends into account, a study was carried out to assess the sustainable development of the EU countries in the implementation of the tasks included in Goal 9 of Agenda 2030. The basis of this research was a set of 14 selected indicators. A proprietary methodology was applied to the research, which included the use of a MCDM methods. In addition to determining the level of sustainable development of individual EU–27 countries and their ranking, the relationship between the level of implementation of Goal 9 of Agenda 2030 and the basic economic, environmental parameters and the DESI digitization index of the studied countries was determined.

The conducted research and the results have provided a lot of new information and knowledge on the implementation of the 2030 Agenda's Goal 9 for sustainable development in the EU–27 countries, divided into countries included in the "old" and "new" EU. On this basis, a number of conclusions and recommendations and policy implications can be formulated. Among the most important of these are:

- For the objective determination of the values of weights for the adopted indicators and the determination of the level of sustainable development and the ranking of the studied countries, it is reasonable to use more than one analytical method and take into account the average value in further analyses.
- The leaders in terms of the implementation of Goal 9 of Agenda 2030, i.e., "Industry, Infrastructure and Innovation", for the entire analyzed period, are six countries, included in the so-called "old EU–14", namely: Denmark, Germany, Luxembourg, the Netherlands, Finland, Sweden.
- Countries with a low level of implementation of the sustainable development economy are Bulgaria and Greece.
- Developed countries, included in the "old EU–14", are mainly in the top two topological groups and perform best in terms of the implementation of Goal 9 of the 2030 Agenda.
- The designated rankings of the EU–27 countries show a high variability in the positions of individual countries, which indicates the dynamic changes taking place in the EU–27 economy. The biggest changes in the period under review were recorded by Cyprus (promotion from place 21 to 13, through places 20, 17 and 15). Large variations in the positions held also occurred in the case of Spain, Estonia, Slovakia.
- The results obtained indicate that the EU–27 countries between 2015–2020 have significantly improved their situation in terms of achieving Goal 9, measured by the value of the SDG_9 index.
- The results were impacted by the selection of indicators included in the study, as evidenced by the comparison of the ranking obtained from the survey and the ranking associated with the monitoring of Sustainable Development Goals. In this study, a set of 14 indicators was used, while in the (Sustainable Development Report, 2015–2020) ranking only 10. However, it can be said that the greater the number of indicators included in the study, the more accurate the assessment of a country, and thus also the more reliable the result.
- The SDG_9 indicator determined in the study for the EU–27 countries for the period 2015–2020 shows a positive statistically significant relationship with the values of GDP per capita, R&D expenditures (as % of GDP), energy productivity, DESI digitization index, as well as a negative statistically significant relationship with greenhouse gas emissions

in relation to GDP values. This confirms the view that the development of an innovative, sustainable economy is a complex process that depends on many factors. The basis, however, is investment in science and the training and development of competent human resources. Thus, the results show the direction of EU policy.

– The results also indicate the need for the EU–27 to develop and implement a more solidarity-based economic, environmental and social policy that takes into account the problems of the new EU countries. Without the help of developed countries, it will be very difficult for these countries to catch up. Also, the emerging concept of a two-speed European Union is unacceptable to these countries.

The research conducted and the results obtained significantly enrich the existing knowledge in the field of building a sustainable economy in the EU countries. They also indicate the role and importance of infrastructure, innovation and digitally based industry. The development of all these areas must take into account the requirements for the environment, and thus also ensure the possibility of development for future generations.

The results also provide ample opportunities to assess the progress of individual countries in the process of implementing Goal 9 of Agenda 2030, which can be the basis for the EU development strategy and the formulation of assumptions for policies to support innovation, digitization of industry or the development of infrastructure (both digital and transport).

Since the least developed countries (EU–13 plus Greece), are at the bottom of the ranking, it becomes necessary for the EU to become more politically, economically and institutionally involved in the development of a sustainable economy in these countries, and to build long-term strategies for their development. An important element, taken into account in these processes, must also be the social factor. Thus, the strategies being developed must not focus solely on economic growth, but rather on a broad process of structural transformation that will help create jobs while reducing environmental damage and increasing the efficiency of the economy.

Thus, the conclusions of the research can provide guidelines and even demands for the EU member states for the coming years, regarding the planning of measures to strengthen innovation, infrastructure development and industrial digitization within the framework of sustainable development policies.

It also seems reasonable to conduct further research with regard to the assessment of the implementation of Goal 9 of Agenda 2030, particularly with regard to studying the impact of the individual indicators considered in this assessment on the value of the Sustainable Development Index (SDG_9).

As with any research, the presented study also has limitations, which may also indicate directions for potential future research. First of all, the study includes a set of 14 indicators related to the implementation of UN Agenda 2030 Goal 9, which in the Eurostat database are used to monitor this goal. However, it is reasonable to check whether a different (e.g., smaller) number of indicators influences the outcome of the assessment. It would also be advisable to analyse in more detail the relationship between the value of this index and the environmental and energy parameters of individual EU countries, taking into account the division into developed and developing. This study did not examine whether economic growth drives innovation, industrialization and infrastructure development or whether the reverse is true. It only examined the existence of such a relationship. It is therefore necessary to complete this part of the study. It is also advisable to address more broadly the links between economic growth itself and innovation, industrialization and infrastructure development, particularly with regard to selected economic sectors and regions in each country. Linking Goal 9 of the UN's Agenda 2030 with regional policies can provide a lot of interesting information on sustainable development.

In summary, the topic undertaken is current and important for the development of the EU, and the research carried out broadens the knowledge of the implementation of the extremely important goal of the UN Agenda 2030. The results indicate further great possibilities for multifaceted study of this issue, which, according to the authors, is and will be increasingly important for the economic and social development of the world, now already inseparable from climate policy.

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Annex

Table 1. Summary of indicators adopted for the study

Indicator	Symbol
Total intramural R&D expenditure by business enterprise sector, Euro per inhabitant	I1
Total intramural R&D expenditure by government sector, Euro per inhabitant	I2
Total intramural R&D expenditure by higher education sector, Euro per inhabitant	I3
R&D personnel by sector, Percentage of population in the labor force - numerator in full-time equivalent	I4
Employment in high- and medium-high technology manufacturing sectors, % of total employment	I5
Employment in knowledge-intensive service sectors, % of total employment	I6
Patent applications to the European Patent Office, per million inhabitants	I7
Tertiary educational attainment, %	I8
Science and technology graduates, Per thousand inhabitants	I9
Share of buses and trains in inland passenger transport, %	I10
Share of rail and inland waterways in inland freight transport, %	I11
Level of internet access, % of households	I12
Individuals aged 55 to 74 years old who have basic or above basic digital skills, %	I13
Enterprises using any computer network for sales (at least 1%), % of enterprises	I14

Table 2. Descriptive statistics of the analyzed indicators between 2015–2020

Indicator	Descriptive statistics	2015	2016	2017	2018	2019	2020
I1	Vt_c (%)	102.73	102.11	99.24	95.73	93.67	92.46
	At_c	0.85	0.87	0.84	0.79	0.75	0.78
I2	Vt_c (%)	118.11	118.36	108.08	108.04	101.12	99.21
	At_c	3.60	3.05	2.71	2.73	2.36	2.28
I3	Vt_c (%)	94.79	100.40	96.80	92.03	88.45	90.16
	At_c	1.48	1.41	1.34	1.36	1.34	1.50
I4	Vt_c (%)	45.71	45.46	42.56	39.91	39.38	37.72
	At_c	0.26	0.27	0.10	-0.06	-0.08	-0.11
I5	Vt_c (%)	59.50	58.96	60.69	61.23	60.48	59.49
	At_c	0.76	0.78	0.82	0.80	0.84	0.89
I6	Vt_c (%)	19.06	18.72	18.25	18.78	18.94	18.83
	At_c	0.16	0.15	0.10	0.16	0.27	0.20
I7	Vt_c (%)	129.61	144.20	138.96	127.12	124.00	118.59
	At_c	1.71	2.52	2.24	1.57	1.43	1.33
I8	Vt_c (%)	21.59	21.09	20.72	20.63	20.79	21.16
	At_c	0.23	0.13	0.12	0.13	0.02	0.02
I9	Vt_c (%)	30.72	35.13	30.94	34.18	35.59	36.87
	At_c	-0.06	0.53	0.06	0.59	0.63	0.83
I10	Vt_c (%)	24.45	24.03	25.18	24.67	23.59	24.39
	At_c	0.92	0.94	0.82	0.84	0.74	0.80

Table 2. Continued

Indicator	Descriptive statistics	2015	2016	2017	2018	2019	2020
I11	Vt_c (%)	63.66	63.01	62.81	63.10	64.03	60.55
	At_c	0.75	0.73	0.67	0.77	0.73	0.49
I12	Vt_c (%)	11.67	10.48	9.62	7.13	6.50	5.38
	At_c	-0.04	0.04	0.04	-0.16	-0.25	-0.55
I13	Vt_c (%)	60.05	59.95	53.89	49.51	47.81	46.49
	At_c	0.93	1.09	0.96	0.79	0.75	0.74
114	Vt_c (%)	38.73	34.74	34.26	35.19	36.36	34.25
	At_c	0.13	0.01	0.17	0.42	0.50	0.48

where: Vt_c is the coefficient of variation and At_c is the coefficient of asymmetry or skewness.

Table 3. Values of indices of the dynamics of change for indicators characterizing sustainable development in the EU countries (%)

	I1	I2	I3	I4	I5	I6	I7	I8	I9	I10	I11	I12	I13	I14
UE-27 average	157	112	124	122	106	104	127	111	110	98	94	113	121	133
UE-14 average	130	121	115	114	100	104	117	113	115	100	97	109	118	123
UE-13 average	187	101	134	130	112	105	138	108	105	96	91	117	123	143
Belgium	159	149	132	131	96	105	115	113	118	99	86	111	105	159
Bulgaria	115	155	139	119	110	101	169	104	90	91	109	134	111	115
Czechia	146	109	113	121	103	108	95	106	94	101	86	111	126	146
Denmark	105	151	117	99	94	100	123	110	118	91	90	103	93	105
Germany	114	122	123	113	102	106	102	119	109	106	88	107	114	114
Estonia	187	143	128	113	119	107	176	104	112	91	74	102	93	187
Ireland	143	114	132	98	79	104	151	108	134	109	80	108	153	143
Greece	207	114	122	124	131	107	150	109	98	91	200	118	211	207
Spain	124	107	111	117	100	104	116	116	93	83	71	120	129	124
France	112	100	106	111	93	103	97	110	118	98	80	110	103	112
Croatia	163	141	231	154	113	107	265	119	123	112	115	110	129	163
Italy	122	118	108	138	105	103	118	115	125	96	89	117	110	122
Cyprus	392	105	146	167	113	104	158	106	98	99	87	131	138	392
Latvia	179	105	144	122	138	103	104	111	109	89	71	118	86	179
Lithuania	267	140	101	137	124	109	133	103	101	87	98	121	128	267
Luxembourg	98	80	117	95	88	108	85	120	124	102	99	97	68	98
Hungary	153	109	156	158	105	99	114	96	193	89	98	116	100	153
Malta	130	3	114	98	97	104	58	126	66	97	87	111	100	130
Netherlands	126	111	110	112	100	101	87	116	115	104	93	101	114	126
Austria	108	178	108	112	98	103	112	107	111	108	91	110	114	108
Poland	228	14	205	163	102	103	85	98	83	90	88	118	123	228
Portugal	179	111	115	138	110	106	179	127	117	105	101	120	140	179
Romania	181	113	67	105	113	106	189	98	117	95	88	126	186	181
Slovenia	112	118	140	109	111	107	137	111	103	96	99	115	144	112
Slovakia	174	64	54	129	106	105	114	125	78	108	80	109	138	174
Finland	114	106	114	104	106	105	94	109	112	107	96	107	108	114
Sweden	112	139	94	108	95	103	109	106	112	105	101	103	94	112

Table 4. Relative changes of weights for individual indicators during the period under review

Indicator	Coefficient of variation 2015–2020	Dynamic coefficient of indicator weights				
		2016/2015	2017/2016	2018/2017	2019/2018	2020/2019
I1	3%	2%	6%	-8%	-1%	0%
I2	4%	4%	4%	-3%	4%	-1%
I3	3%	-2%	-4%	6%	2%	-3%
I4	4%	-1%	-1%	-4%	-2%	-1%
I5	6%	3%	-4%	-9%	0%	0%
I6	4%	5%	1%	-9%	-1%	-1%
I7	5%	-5%	12%	-3%	0%	2%
I8	6%	0%	-9%	1%	-4%	-2%
I9	6%	0%	4%	5%	0%	5%
I10	2%	2%	-2%	3%	-3%	0%
I11	2%	-1%	0%	-4%	2%	1%
I12	3%	1%	3%	-4%	-3%	-3%
I13	2%	-2%	1%	0%	3%	1%
I14	2%	0%	1%	3%	-3%	-1%

Table 5. Summary of the values of the indices of sustainable development determined for the EU–27 countries, together with their position in the ranking for 2015

Country	Method and place in ranking						Distance − difference between highest and lowest position
	EDAS As_i	Rank	WASPAS Q_i	Rank	TOPSIS P_i	Rank	
Belgium	0.563	10	0.263	8	0.324	8	2
Bulgaria	0.000	27	0.134	26	0.073	27	1
Czechia	0.480	13	0.216	11	0.224	11	2
Denmark	0.854	3	0.332	3	0.465	4	1
Germany	0.796	5	0.311	4	0.470	3	2
Estonia	0.738	7	0.187	14	0.137	18	11
Ireland	0.650	8	0.236	10	0.268	10	2
Greece	0.216	24	0.129	27	0.099	23	4
Spain	0.480	13	0.173	17	0.162	15	4
France	0.592	9	0.249	9	0.302	9	0
Croatia	0.432	17	0.139	24	0.108	22	7
Italy	0.384	21	0.170	19	0.159	16	5
Cyprus	0.288	22	0.135	25	0.082	25	3
Latvia	0.408	18	0.165	20	0.081	26	8
Lithuania	0.216	24	0.173	18	0.120	20	6
Luxembourg	1.000	1	0.349	1	0.738	1	0
Hungary	0.408	18	0.182	16	0.148	17	2
Malta	0.533	12	0.183	15	0.208	13	3
Netherlands	0.971	2	0.298	6	0.435	6	4
Austria	0.563	10	0.293	7	0.372	7	3
Poland	0.408	18	0.160	21	0.118	21	3
Portugal	0.264	23	0.146	22	0.126	19	4
Romania	0.216	24	0.141	23	0.088	24	1
Slovenia	0.456	16	0.215	12	0.214	12	4
Slovakia	0.480	13	0.188	13	0.178	14	1
Finland	0.796	5	0.309	5	0.452	5	0
Sweden	0.825	4	0.337	2	0.484	2	2

Table 6. The final values of the SDG_9 index and the ranking of the EU–27 countries in each of the years studied

Country	Values of aggregate SDG₉ index with the ranking (R) of EU-27 countries											
	2015		2016		2017		2018		2019		2020	
	SDG_9	R	SDG_9	R	SDG_9	R	SDG_9	R	SDG_9	R	SDG_9	R
Belgium	0.494	9	0.510	8	0.551	9	0.625	8	0.666	8	0.699	7
Bulgaria	0.008	27	0.000	27	0.000	27	0.000	27	0.000	27	0.000	27
Czechia	0.353	13	0.370	12	0.406	12	0.472	13	0.442	14	0.437	14
Denmark	0.789	3	0.764	4	0.881	3	0.888	4	0.913	4	0.976	3
Germany	0.740	5	0.714	5	0.879	4	0.905	3	0.912	5	1.000	1
Estonia	0.368	11	0.383	11	0.435	11	0.495	11	0.442	13	0.414	15
Ireland	0.517	8	0.493	10	0.527	10	0.596	10	0.610	9	0.655	9
Greece	0.085	26	0.086	26	0.104	26	0.115	26	0.114	26	0.056	26
Spain	0.271	16	0.325	13	0.392	13	0.395	14	0.471	12	0.635	10
France	0.477	10	0.495	9	0.582	8	0.598	9	0.570	10	0.589	11
Croatia	0.195	20	0.208	20	0.169	25	0.250	21	0.170	25	0.232	23
Italy	0.233	18	0.281	17	0.385	14	0.364	15	0.327	17	0.369	17
Cyprus	0.110	24	0.152	24	0.249	20	0.333	17	0.379	15	0.480	13
Latvia	0.177	21	0.204	21	0.225	21	0.243	22	0.247	21	0.347	20
Lithuania	0.140	23	0.159	23	0.193	23	0.199	25	0.226	23	0.162	25
Luxembourg	1.000	1	1.000	1	1.000	1	1.000	1	1.000	1	0.996	2
Hungary	0.254	17	0.278	18	0.352	17	0.338	16	0.341	16	0.367	18
Malta	0.366	12	0.306	16	0.368	16	0.325	18	0.312	19	0.392	16
Netherlands	0.796	2	0.776	2	0.883	2	0.956	2	0.944	3	0.974	4
Austria	0.586	7	0.552	7	0.668	7	0.717	7	0.704	7	0.684	8
Poland	0.206	19	0.261	19	0.306	19	0.314	19	0.319	18	0.363	19
Portugal	0.162	22	0.177	22	0.207	22	0.207	24	0.179	24	0.198	24
Romania	0.098	25	0.126	25	0.176	24	0.225	23	0.233	22	0.235	22
Slovenia	0.327	14	0.322	14	0.377	15	0.492	12	0.493	11	0.501	12
Slovakia	0.302	15	0.314	15	0.347	18	0.305	20	0.255	20	0.311	21
Finland	0.728	6	0.689	6	0.782	6	0.856	6	0.830	6	0.962	5
Sweden	0.761	4	0.764	3	0.864	5	0.879	5	0.944	2	0.930	6

Table 7. Groups of similar countries in the EU–27 in terms of supporting innovation, building stable infrastructure and promoting sustainable industrialization by year

Year	Class 1	Class 2	Class 3	Class 4
2015	Denmark, Germany, Luxembourg, Netherlands, Finland, Sweden	Belgium, Estonia, Ireland, France, Austria	Czechia, Spain, Croatia, Italy, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Slovenia, Slovakia	Bulgaria, Greece, Romania, Cyprus
2016	Denmark, Germany, Luxembourg, Netherlands, Finland, Sweden	Belgium, Ireland, France, Austria	Czechia, Estonia, Spain, Croatia, Italy, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Slovenia, Slovakia	Bulgaria, Greece, Romania
2017	Denmark, Germany, Luxembourg, Netherlands, Finland, Sweden	Belgium, Ireland, France, Austria	Czechia, Estonia, Spain, Italy, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Slovenia, Slovakia	Bulgaria, Greece, Romania, Croatia
2018	Denmark, Germany, Luxembourg, Netherlands, Finland, Sweden	Belgium, Estonia, Ireland, France, Austria, Slovenia	Czechia, Spain, Croatia, Italy, Cyprus, Latvia, Hungary, Malta, Poland, Portugal, Romania, Slovakia	Bulgaria, Greece, Lithuania
2019	Denmark, Germany, Luxembourg, Netherlands, Finland, Sweden	Belgium, Ireland, France, Austria, Slovenia, Slovakia	Czechia, Estonia, Spain, Italy, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland	Bulgaria, Greece, Romania, Portugal, Croatia
2020	Denmark, Germany, Luxembourg, Netherlands, Finland, Sweden	Belgium, Ireland, Spain, France, Austria	Czechia, Estonia, Croatia, Italy, Cyprus, Latvia, Hungary, Malta, Poland, Romania, Slovenia, Slovakia	Bulgaria, Greece, Portugal, Lithuania
2015-2020 average	Denmark, Germany, Luxembourg, Netherlands, Finland, Sweden	Belgium, Ireland, France, Austria	Czechia, Estonia, Spain, Croatia, Italy, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Portugal, Romania, Slovenia, Slovakia	Bulgaria, Greece

Table 8. Spearman's Rank-Order Correlation and Kendall rank correlation coefficient

	Kendall rank correlation coefficient		Spearman's Rank-Order Correlation	
	SDGs 9 index 2015-2020 average	*p*	SDGs 9 index 2015-2020 average	*p*
GDP per capita, Euro	**0.698**	**0.000**	**0.878**	**0.000**
R&D, % of GDP	**0.561**	**0.000**	**0.752**	**0.000**
Energy productivity, Euro per kilogram of oil equivalent	**0.373**	**0.006**	**0.578**	**0.002**
Greenhouse gases emission from NACE activity, thousand tons	0.066	0.631	0.118	0.556
Greenhouse gases emission/GDP, thousand tons/Million Euro	**-0.459**	**0.001**	**-0.679**	**0.000**
Digitalization index (DESI)	**0.510**	**0.000**	**0.694**	**0.000**

Table 9. Comparison of the SDG_9 ranking with the Sustainable Development Report ranking for the EU–27 countries

Country	Ranking	2015	2016	2017	2018	2019	2020
Belgium	Goal 9 Score (Report)	10	6	7	7	6	6
	SDG 9 (calculations)	9	8	9	8	8	7
Bulgaria	Goal 9 Score (Report)	26	26	27	27	27	26
	SDG 9 (calculations)	27	27	27	27	27	27
Czechia	Goal 9 Score (Report)	15	15	14	13	13	13
	SDG 9 (calculations)	13	12	12	13	14	14
Denmark	Goal 9 Score (Report)	1	1	2	1	2	2
	SDG 9 (calculations)	3	4	3	4	4	3
Germany	Goal 9 Score (Report)	5	4	6	5	5	5
	SDG 9 (calculations)	5	5	4	3	5	1
Estonia	Goal 9 Score (Report)	13	13	13	14	14	14
	SDG 9 (calculations)	11	11	11	11	13	15
Ireland	Goal 9 Score (Report)	9	11	10	12	12	11
	SDG 9 (calculations)	8	10	10	10	9	9
Greece	Goal 9 Score (Report)	24	24	18	18	19	19
	SDG 9 (calculations)	26	26	26	26	26	26
Spain	Goal 9 Score (Report)	11	9	11	10	9	9
	SDG 9 (calculations)	16	13	13	14	12	10
France	Goal 9 Score (Report)	7	5	8	8	8	8
	SDG 9 (calculations)	10	9	8	9	10	11
Croatia	Goal 9 Score (Report)	17	19	25	23	23	23
	SDG 9 (calculations)	20	20	25	21	25	23
Italy	Goal 9 Score (Report)	12	12	12	11	11	11
	SDG 9 (calculations)	18	17	14	15	17	17
Cyprus	Goal 9 Score (Report)	22	21	15	17	15	16
	SDG 9 (calculations)	24	24	20	17	15	13

Table 9. Continued

Country	Ranking	2015	2016	2017	2018	2019	2020
	SDG 9 (calculations)	24	24	20	17	15	13
Latvia	Goal 9 Score (Report)	23	25	24	22	22	22
	SDG 9 (calculations)	21	21	21	22	21	20
Lithuania	Goal 9 Score (Report)	19	17	21	25	24	23
	SDG 9 (calculations)	23	23	23	25	23	25
Luxembourg	Goal 9 Score (Report)	7	7	9	9	10	10
	SDG 9 (calculations)	1	1	1	1	1	2
Hungary	Goal 9 Score (Report)	21	22	18	20	20	20
	SDG 9 (calculations)	17	18	17	16	16	18
Malta	Goal 9 Score (Report)	14	14	22	21	21	21
	SDG 9 (calculations)	12	16	16	18	19	16
Netherlands	Goal 9 Score (Report)	4	3	5	6	7	7
	SDG 9 (calculations)	2	2	2	2	3	4
Austria	Goal 9 Score (Report)	6	10	3	3	3	3
	SDG 9 (calculations)	7	7	7	7	7	8
Poland	Goal 9 Score (Report)	24	16	16	15	17	18
	SDG 9 (calculations)	19	19	19	19	18	19
Portugal	Goal 9 Score (Report)	20	23	20	19	18	17
	SDG 9 (calculations)	22	22	22	24	24	24
Romania	Goal 9 Score (Report)	27	27	26	26	26	26
	SDG 9 (calculations)	25	25	24	23	22	22
Slovenia	Goal 9 Score (Report)	16	17	17	16	15	15
	SDG 9 (calculations)	14	14	15	12	11	12
Slovakia	Goal 9 Score (Report)	18	20	23	24	25	25
	SDG 9 (calculations)	15	15	18	20	20	21
Finland	Goal 9 Score (Report)	2	2	1	2	1	1
	SDG 9 (calculations)	6	6	6	6	6	5
Sweden	Goal 9 Score (Report)	3	8	3	4	4	4
	SDG 9 (calculations)	4	3	5	5	2	6

Table 10. Values of Person's correlation coefficients between the positions obtained in the Sustainable Development Report rankings and in this study

2015	2016	2017	2018	2019	2020
0.92	0.901	0.90	0.89	0.88	0.88

Figure 1. The course of the ongoing research investigation

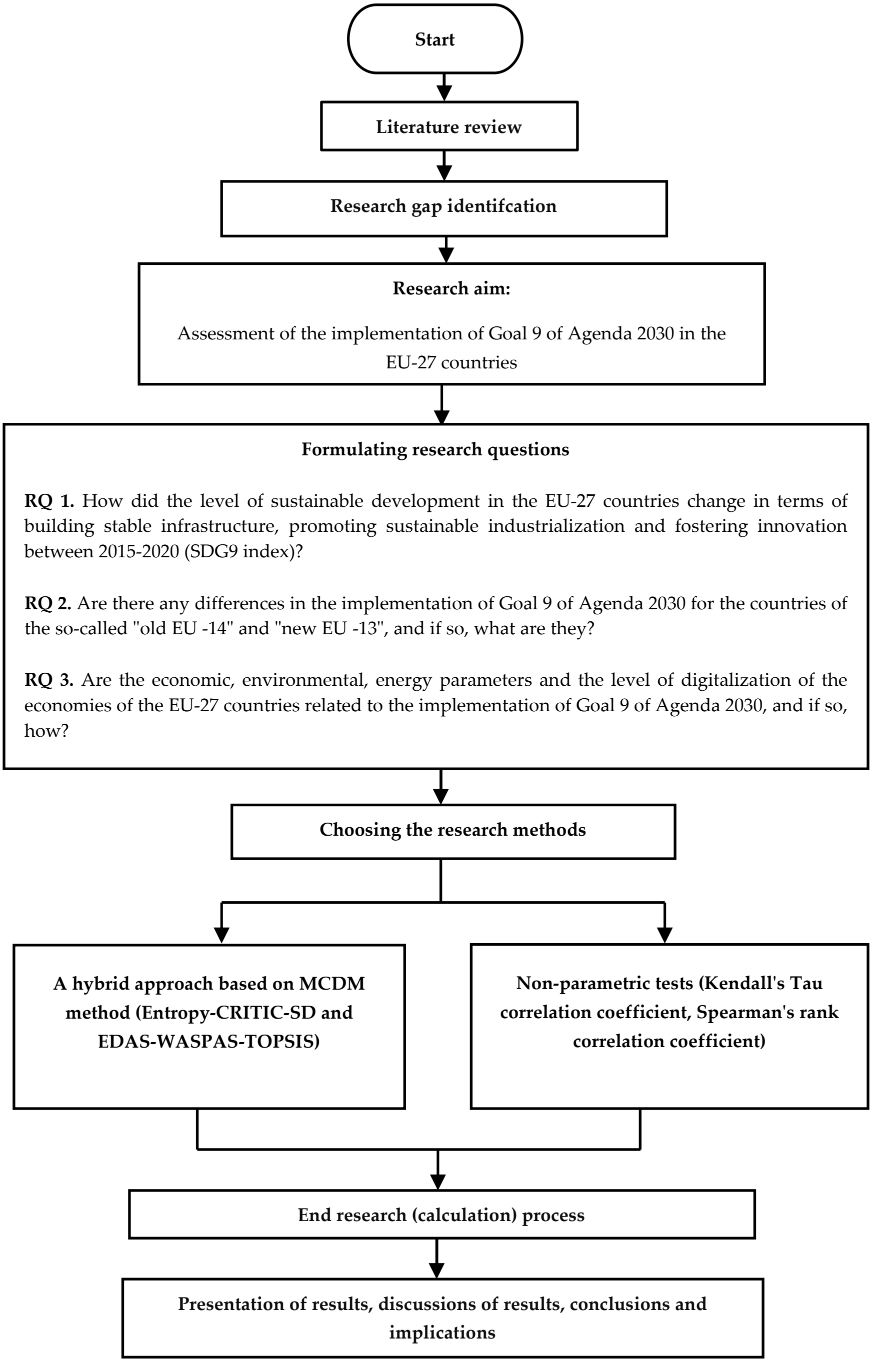


Figure 2. Multi MCDM methods approach to assessing the level of sustainable development of EU countries

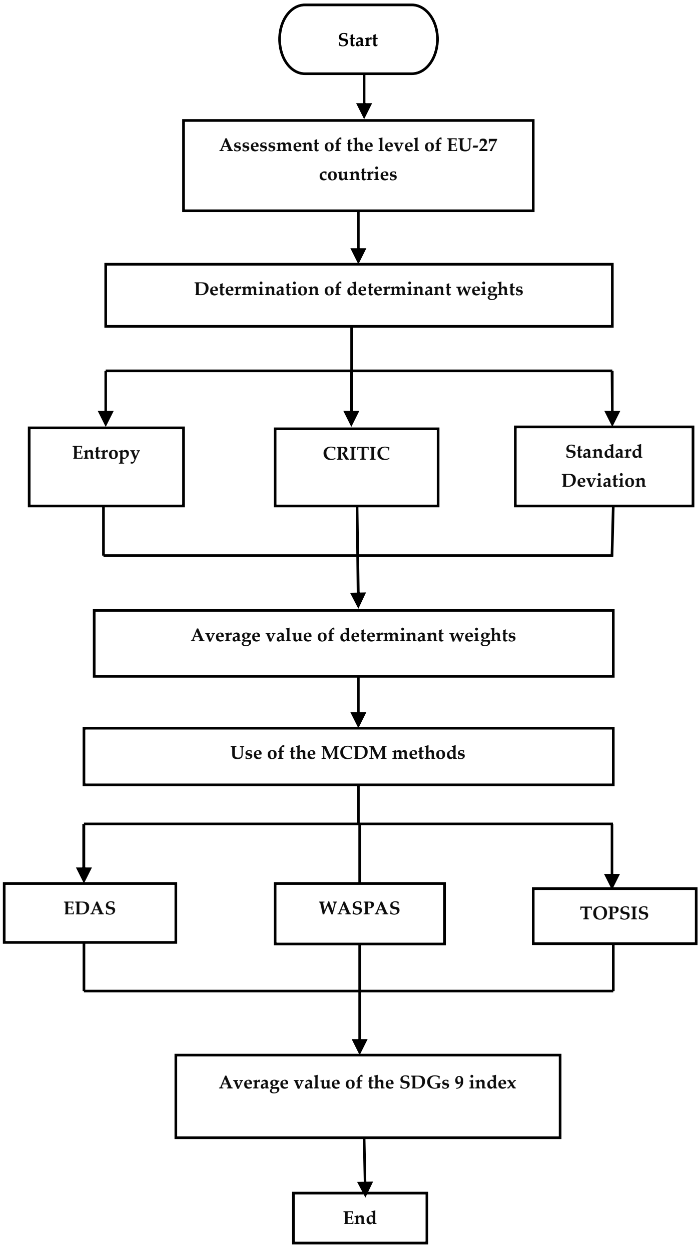
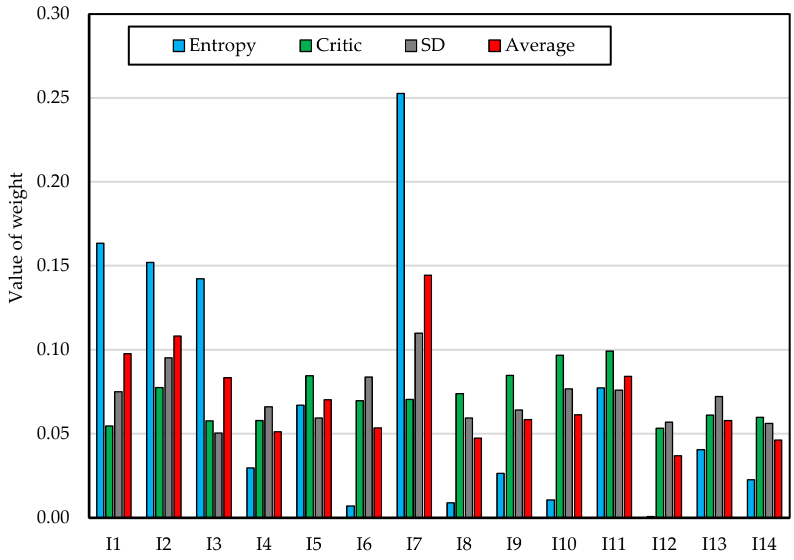
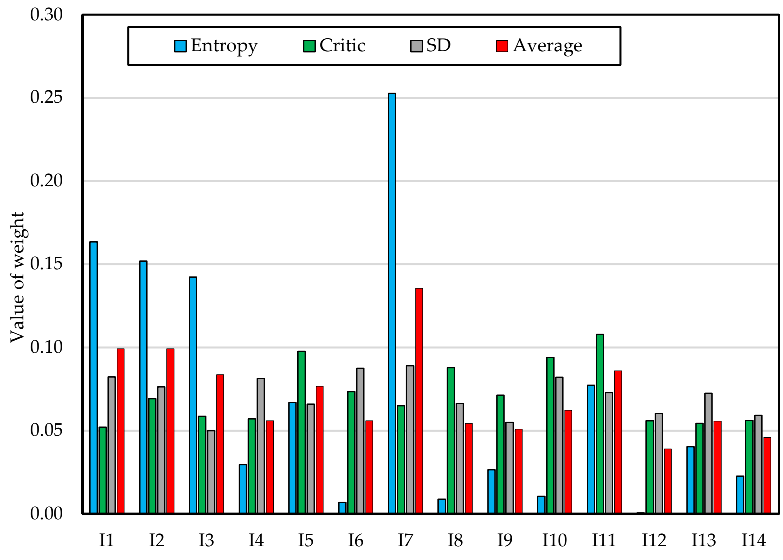


Figure 3. The value of weights for the studied indicators determined by the CRITIC, Entropy and SD methods, as well as the average values of these indicators for 2015 (a) and 2020 (b)



a



b

Figure 4. Average values of weights for the indicators adopted for the study

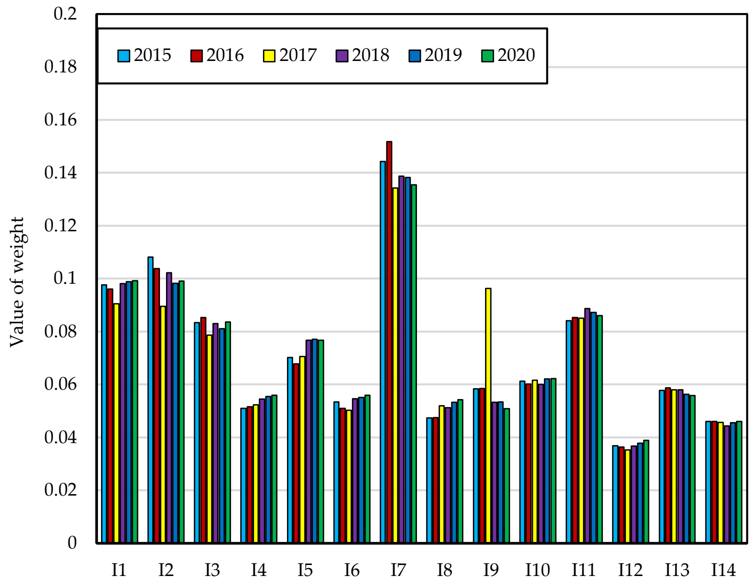


Figure 5. Summary of the average values of the *SDG*₉ index between 2015–2020 and the position in the ranking for the whole analyzed period