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Building resilient infrastructure, supporting sustainable industrialization, and fostering innovation (SDG 9) in selected European countries: spatial and taxonomic analysis

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Abstract. Sustainable Development Goals (SDGs) consist of 17 goals and 169 targets to be met by the end of 2030. Since the European Union (EU) members are also included in the 2030 Agenda for Sustainable Development set by the United Nations (UN) countries, it is vital to analyze the Sustainable Development performance of the EU economies. This paper focuses on SDG 9, which aims to build resilient infrastructure, support inclusive and sustainable industrialization, and foster innovation. This research analyzes the industry, innovation and infrastructure indicators in selected European economies. The main aim of this paper is to assess the performance of the European economies in SDG 9 and to verify whether there are any spatial dependencies among countries. Applying the taxonomic measure of development and its spatial version to the group of 29 countries from Europe shows that Sweden and Denmark were the leading countries in SDG 9 in 2013 and 2019. Eastern and South-Western Europe was characterized by the lowest level of SDG 9 in 2013 and 2019. The level of SDG 9 increased over the period 2013–2019.

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Contents:

1. Introduction

Sustainable Development Goals (SDGs) were established at the summit in New York in 2015, where the leaders of the UN members signed the document Transforming our world: Agenda for Sustainable Development – 2030. SDGs are committed to taking action to reduce poverty; ensure access to education, food, and clean water; support equal opportunities; and promote human rights, peace and stability in the world, environmental protection, climate change mitigation, and access to sustainable energy sources (International Council for Science, 2017; Leal Filho et al., 2019; Miola & Schiltz, 2019; Herath & Poon, 2021). There are 17 Sustainable Development Goals and 169 related activities to be achieved by all parties: governments, international organizations, non-governmental organizations, the science and business sector, as well as citizens. They are concentrated around the so-called '5xP': people, planet, prosperity, peace, and partnership (Ghosh & Rajan, 2019; Tremblay et al., 2020; Carlsen & Bruggemann, 2022).

One of the SDGs – SDG 9 – is focused on building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation. This goal serves as a response to the problems of all countries, but primarily low-income and developing ones. There are still many people with limited or no access to basic sanitation, including the problem of the lack of access to clean water (Tortajada & Biswas, 2018; Pichel et al., 2019; Bernal et al., 2021). In some low-income countries, especially African ones, the lack of proper infrastructure dramatically decreases productivity levels in their economies (in some cases, even by 40%). In addition, there is also an issue with a shortage of constant electricity supply in some developing countries (Shahsavari & Akbari, 2018; Sangwan & Bhatia, 2020; Mhlanga, 2021). Another constraint is the lack of access to the Internet in some developing countries (Khan et al., 2018; Villapol et al., 2018; Graham, 2019). Therefore, SDG 9 proposes the following targets to mitigate these problems: 9.1: Develop sustainable, resilient and inclusive infrastructure; 9.2: Promote inclusive and sustainable industrialization; 9.3: Increase the access of small-scale industrial and other enterprises; 9.4: Upgrade infrastructure and retrofit industries to make them sustainable; 9.5: Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries; 9.A Facilitate sustainable and resilient infrastructure development in developing countries; 9.B Support domestic technology development, research and innovation in developing countries; 9.C Increase access to information and communications technology (Mantlana & Maoela, 2020; UNSTATS, 2022). Although these targets are set in order to improve the performance of innovation, infrastructure and industrialization worldwide, their formulation is sometimes questionable (Eisenmenger et al., 2020; Giannetti et al., 2020; Velazquez, 2021). As Adshead, Thacker, Fuldauer & Hall (2019) noted, some of the targets do not specify the contribution to particular sectors; e.g., target 9.1 does not indicate which infrastructure should be further developed in the first place. There are no importances or priorities given to specific projects, so it might be the case that some targets are too general. In addition, improving innovation by injecting more money into Research and Development (R&D) is very often wishful thinking. One should treat increased spending on R&D with some caution since it does not automatically lead to an increase in innovation and competitiveness (Niklasson, 2019; Pelikánová, 2019; Sagar & van der Zwaan, 2006).

Many scientific papers elaborate on the essence of SDGs and compare the results of different countries. Since most existing research concerns indexing and analyses on country-specific performance, there is a gap in analyzing specifically SDG 9 in the spatial context. Therefore, this paper aims to assess the performance of the European economies in SDG 9 and verify whether there are any spatial dependencies among countries. The research hypothesis is thus as follows: H: A country's geolocation plays an important role in shaping SDG 9. There are two research questions related to this research paper: Q.1. What is the performance of the EU countries in SDG 9 in 2013–2019? Q.2. Are there any spatial dependencies among the EU countries in SDG 9 in 2013–2019?

2. Literature review

Although SDGs have been widely analyzed in the scientific literature, the particular focus on SDG 9 is still underrepresented. SDG is a concept that aims to foster economic growth, which should be in line with both social progress and environmental concerns. As the EU countries act together in many socio-economic and environmental activities, it is valuable to address their performance in SDG 9, which concerns innovation, industrialization and infrastructure. This section provides an overview of research conducted on this topic, including methods, data and results. Previous research on this topic includes the paper by Kynčlová, Upadhyaya and Nice (2020), where the SDG-9 index benchmarked 128 economies from 2000 to 2016. This research showed that the top five leading countries in SDG 9 in the 2016 ranking were Ireland, Germany, the Republic of Korea, Switzerland and Japan. The SDG-9 index showed that industrialized economies are better off in all dimensions in the composite metric of the attainment of that goal. Hence, developing economies at the beginning phase of industrialization have more opportunities to obtain higher sustainable economic growth.

Another extensive study considered the SDG 9 Progress Index in 124 countries. The SDG 9 Progress Index incorporates five industry-related measures into a multidimensional index that presents the relative progress of economies in meeting SDG 9 targets. Its findings show that between 2000 and 2016, 58 countries made progress in meeting their targets, while 66 regressed. This index indicated that less-developed and developing countries made better progress than industrialized and emerging industrial economies. Bangladesh, Myanmar, Slovakia, Vietnam and Poland were the leading countries with the highest gains. The five countries that made the greatest regresses were China, Luxembourg, Singapore, Canada and Israel (Saieed et al., 2021).

It is important to mention the SDG index published by the Sustainable Development Solutions Network (SDSN), which is an essential document for measuring not only the overall index performance but also specific goals (Lafortune et al., 2022). SDG 9 is represented with the following nine measures: gross domestic expenditure on R&D, R&D personnel, patent applications to the European Patent Office, households with broadband access, gap in Internet access, urban vs. rural areas, population with at least basic digital skills, logistics performance index: quality of trade and transport related infrastructure, the Times Higher Education Universities Ranking: average score of the top 3 universities, articles published in academic journals. Although SDSN's concept is reasonably well-established and widely applicable (not only in academia but also by policymakers), SDG 9 seems to be missing some crucial aspects from the industrial sphere. There is a significant emphasis on innovation and some on infrastructure. However, the industry is underestimated since it lacks industrial targets.

Topical research on SDG 9 in the EU countries conducted by Grodzicki (2018) focused on the following seven indicators of SDG 9: gross domestic expenditure on R&D by sector, employment in high- and medium-high technology manufacturing sectors and knowledge-intensive service sectors, R&D personnel by sector, patent applications to the European Patent Office, share of collective transport modes in total passenger land transport by vehicle, share of rail and inland waterways activity in total freight transport, average carbon dioxide (CO_2) emissions per km from new passenger cars. The analysis was conducted for the EU countries in the period 2008–2016 using the taxonomic measure of development, linear ordering, and spatial trend models. The results indicated that, on average, old EU member states performed much better in SDG 9 than new EU member states. Moreover, the richer the EU country (GDP per capita), on average, the more advanced it was in SDG 9. Although this paper aimed at assessing the spatial dependencies, the results only confirmed a second-degree spatial trend, implying that Scandinavian and western EU countries scored, on average, the highest values in SDG 9 while central and eastern EU countries were lagging behind. However, no spatial autocorrelation or cluster formation was noted.

Therefore, there is a need for a complex study to assess the performance of EU countries in SDG 9 and to identify any spatial dependencies among them.

3. Materials and methods

In the beginning, two composite indicators are built to evaluate the level of sustainable industry, infrastructure and innovation, which is the core driver for ending poverty and improving all people's living standards. The first is the classical Taxonomic Measure of Development (TMD) proposed by Hellwig (1968), and the second is its modification, considering spatial dependence between diagnostic processes (STMD) offered by Pietrzak (2014).

The base of the taxonomic analyses are the following sets: $\boldsymbol{O}=\{O_1,O_2,\dots,O_n\}$ (set of objects that are the subject of analysis) and $\boldsymbol{X}=\{X_1,X_2,\dots,X_m\}$ (set of variables characterizing objects from the set $\boldsymbol{O}$). In this research, selected European countries are treated as objects, and the selected measures of the industry and innovation level as the characteristics in X are chosen. The process of constructing the classical TMD measure consists of several stages.

Stage 1. Building a data matrix containing potential diagnostic variables:

$$\boldsymbol{X} = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,m} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,m} \\ \vdots & & \ddots & \vdots \\ x_{n,1} & x_{n,2} & \cdots & x_{n,m} \end{bmatrix} \quad (1)$$

where $x_{i,j}$ is the element of the data matrix describing the level of j^{th} characteristics (X_j) for the i^{th} country (O_i).

Stage 2. Determining the final set of the diagnostic industry and innovation variables based on the formal, substantive and statistical criteria. The latter is not obligatory, but in this study, the values of the classical coefficient of variation for variables and Pearson's linear correlation coefficients between them are considered. Firstly, the values of the classical coefficient of variation v_j of the form (2) are calculated:

$$v_j = \frac{s_j}{|\bar{x}_j|} \cdot 100\% \;\; (j = 1, \dots, m), \tag{2}$$

where s_j and $\bar{x}_j$ denote the standard deviation and arithmetic average of the variable X_j. Variables with the value of v_j less than 20% are removed from the $\boldsymbol{X}$. Next, the data matrix overlooks variables highly correlated with each other. Pearson's correlation coefficient at level 0.75 is adopted as the threshold value.

Stage 3. Determining the character of the influence of every variable on the considered process. The variables can be divided into stimulants (positive impact), destimulants (negative effect), and neutral variables. The diagnostic variables with their character of impact are presented in Table 1 at the end of this section.

Stage 4. Establishing weights for all variables. In this study, equal weights are adopted.

Stage 5. Normalization of variables' values. In this research, standardization as a normalization method is adopted. Standardization is the method applied in the classical approach in building the Taxonomic Measure of Development. We also decided to use this method despite the variables' values not being normally distributed, because other methods (for example, unitarization or positional standardization) gave the same final rankings. The standardized values of variables are calculated as follows:

$$X'_j = \frac{X_j - \bar{x}_j}{s_j}. \tag{3}$$

Standardization parameters (arithmetic average – $\bar{x}_j$ and standard deviation – s_j) are calculated based on data covering the entire period to enable the analysis of changes over time.

Stage 6. Specifying the pattern of development. The pattern of development is the vector containing desired values of every variable: $\boldsymbol{Q_0}=[z_{01},z_{02},\dots,z_{0m}]$. This is a maximal value for stimulants but minimal for destimulants:

$$z_{0j} = \begin{cases} \max_i\{x'_{ij}\}, & for\ j \in \{S\} \\ \min_i\{x'_{ij}\}, & for\ j \in \{D\} \end{cases}, \tag{4}$$

where *{S}* and *{D}* are sets of stimulants and destimulants, respectively.

Stage 7. Calculate the value of the TMD measure using the following formula:

$$TMD_i = 1 - \frac{d_{i0}}{d_0}, \tag{5}$$

where d_{i0} is the distance between the i^{th} country and the pattern of development (calculated in this research using Euclidean distance: $d_{i0} = d[\sum^{m}_{j=1}(x'_{ij} - z_{0j})^2]^{0,5}, i=1,\dots,n$), whereas d_0 is the norm of the distances d_{i0} expressed as its arithmetic average plus twice the standard deviation.

Spatial TMD is constructed similarly to this classical one. Additionally, in stage 2 (after determining the final set of the diagnostic variables), processes are transformed to account for spatial dependencies. Firstly, the presence of spatial autocorrelation in the formation of variable values is checked using Moran's I statistics (Moran, 1950; Schabenberger & Gotway, 2005):

$$I = \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \cdot \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\,[y_i - \bar{y}][y_j - \bar{y}]}{\frac{1}{n}\sum_{i=1}^{n}[y_i - \bar{y}]^2} = \frac{n}{S_0} \cdot \frac{\boldsymbol{z}^T\boldsymbol{W}\boldsymbol{z}}{\boldsymbol{z}^T\boldsymbol{z}}, \tag{6}$$

where y_i denotes an observed value of the phenomenon in the region i, $\boldsymbol{z}$ is a column vector with elements $z_i = y_i - \bar{y}$, $\boldsymbol{W}$ is the row-standardized neighborhood matrix characterizing spatial connections between units, and n is the number of regions. The proximity matrix based on the common land border is the most often used connection matrix. Due to the presence of islands (for example Cyprus) in the set of territorial units, this type of neighborhood matrix is not applied. In this study, the neighborhood matrix is created based on the four nearest neighbors criterion, implying that no country is without a neighbor. The use of four nearest neighbors allows a slightly denser matrix to be created than that based on the common border criterion, which strengthens the consideration of spatial dependence. Variables in which spatial autocorrelation does not occur are not changed. For those with a significant spatial autocorrelation, a spatial autoregressive model (6) is estimated (Giuseppe, 2006):

$$\boldsymbol{X_j} = \rho \boldsymbol{W} \boldsymbol{X_j} + \boldsymbol{\varepsilon}. \tag{7}$$

In model (6) $\boldsymbol{X}_j$ is a considered diagnostic variable, ρ is a structural parameter, ε denotes a random component, and $\boldsymbol{W}$ – as above. Next, variables are transformed using the following formula (Pietrzak, 2014):

$$\boldsymbol{Z}_k = (\boldsymbol{I} - \rho \boldsymbol{W})^{-1} \boldsymbol{X}_k = \boldsymbol{V}(\boldsymbol{W}) \boldsymbol{X}_k, \quad (8)$$

where X_k denotes the kth diagnostic variable, $\boldsymbol{V(W)} = (\boldsymbol{I}\text{-}\rho \boldsymbol{W})^{-1}$ is the matrix whose elements show a potential interaction strength between regions due to the variable X_k, and ρ is a parameter estimated based on the model (6) for the k^{th} diagnostic variable. Transformed variables are added to the final data matrix. The remaining steps in constructing STMD are the same as in the classical TMD (see stages 3–7). Based on the values of TMD and STMD, rankings of regions are constructed. Moreover, a concordance of these rankings in the extreme years of investigation is checked using Kendall's τ – Kendall Rank Correlation Coefficient (Abdi, 2007).

Finally, changes in both taxonomic measures over time are investigated. For this purpose, time trend models for panel data with fixed effects are estimated and take the following forms:

$$TMD_{i,t} = \alpha_{0i} + \alpha_1 t + \varepsilon_{i,t}, \quad (9)$$

$$STMD_{i,t} = \beta_{0i} + \beta_1 t + \varepsilon_{i,t}, \quad (10)$$

where $TMD_{i,t}$ and $STMD_{i,t}$ denote values of the classical and spatial TMD respectively in the i^{th} region in time t, t is the time variable, α_{0i}, α_1 are structural parameters, and $\varepsilon_{i,t}$ is a random component of the models.

In the first step of the study, the potential diagnostic variables were chosen. Processes characterizing the level of sustainable industry, infrastructure and innovation (SDG 9) are presented in Table 1.

Variable X_7 is a replacement variable due to no data for Norway in the original process in SDG9 called *Average CO_2 emissions per km from new passenger cars*. Data for the analysis come from the database of the European Statistical Office (EUROSTAT: https://ec.europa.eu/eurostat/web/sdi/industry-innovation-and-infrastructure) (except X_7) and the Our World in Data website (https://ourworldindata.org/co2-emissions). Two processes were determined as destimulants – processes with a negative impact on the analyzed phenomenon. Analysis refers to 29 selected European countries (27 EU countries, United Kingdom, and Norway) in the years 2013–2019.

4. Results

The final set of diagnostic variables was determined, and Table 2 shows basic statistics in the preliminary analysis of diagnostic variables. Values of the

Table 1. List of processes characterized by the level of SDG 9

Symbol	Name of variable	Nature of impact	Reference justifying the nature of impact
$\boldsymbol{X_1}$	Gross domestic expenditure on R&D (% of GDP)	stimulant	Estevão, Lopes and Penela (2023)
$\boldsymbol{X_2}$	R&D personnel (% of the population in the labor force)	stimulant	Estevão, Lopes and Penela (2023)
$\boldsymbol{X_3}$	Patent applications to the European Patent Office (per 1 million inhabitants)	stimulant	Pater and Lewandowska (2015)
$\boldsymbol{X_4}$	Share of buses and trains in total passenger transport (%)	stimulant	Kuc-Czarnecka, Markowicz and Sompolska-Rzechuła (2023)
$\boldsymbol{X_5}$	Air emission intensity from industry (grams per euro)	destimulant	Kuc-Czarnecka, Markowicz and Sompolska-Rzechuła (2023)
$\boldsymbol{X_6}$	Tertiary educational attainment (% of population 25–34)	stimulant	Kuc-Czarnecka, Markowicz and Sompolska-Rzechuła (2023)
$\boldsymbol{X_7}$	Average CO_2 emissions (per 1 inhabitant)	destimulant	Nathaniel and Adeleye (2021)
$\boldsymbol{X_8}$	High-speed Internet coverage (% of households)	stimulant	Kuc-Czarnecka, Markowicz and Sompolska-Rzechuła (2023)

Source: own elaboration, improved version of the standard coefficient of variation (V) did not allow for the rejection of any variable from the set of diagnostics (all are over 20%). Moreover, the correlation analysis showed that only two variables – X_1 and X_2 – are strongly correlated. Pearson's linear correlation coefficient between them is over 0.75. Nonetheless, both were considered in the building of taxonomic measures based on substantive premises. Consequently, all of the potential diagnostic variables were included in the composite indicators. It is also worth noting that most of the variables were spatially autocorrelated. Only for X_7 is Moran's I coefficient not statistically significant. For others, Moran's I is positive, so regions with similar values of individual variables form spatial clusters. Results of the Moran test indicated the need for the construction of the spatial version of TMD.

Figure 1 presents the spatial distributions of all diagnostic variables in 2019 with the division to Moran's plot quarters. Only the last year of the investigation was chosen due to non-significant changes in rankings between 2013 and 2019. The presented maps constitute the confirmation of the concluded dependence between neighboring countries. As we can see, for variables X_1, X_2 and X_3, the considered area is dominated by territorial units surrounded by states with similar values of variables (high-high and low-low groups). An analogous situation appears in the case of variables X_6 and X_8. The biggest diversification is visible for variable X_7, where the number of countries surrounded by units with similar and opposite values of the variable is almost the same. The similarity of countries according to diagnostic variable values shows the relevant influence of the spatial connections in the building of the composite indicator, and these connections can disrupt the real level of SDG9 achievement in particular countries. In a few cases (where variables are stimulants), Slovenia, as one of the countries from the eastern part of Europe, belongs to the high-low group that presents a possible high level of SDG9 achievement despite the low level in neighboring countries. Therefore, in this part of Europe, Slovenia shows hot-spot characteristics. The opposite case holds for Spain (Western Europe), which is a country surrounded by countries with more desirable values of diagnostic variables. So Spain presents the features characteristic of cold-spots.

Table 3 presents the results of the taxonomic analysis. The extreme years of the investigation show values of the classical taxonomic measure of development (TMD) and its spatial modification (STMD). Countries in Table 3 were presented by descending order of TMD values from 2013.

Irrespective of the applied method, Sweden and Denmark were the first two leading countries in SDG 9 in both extreme years of the investigation. Differences in the values of the taxonomic measures between these countries are slight. In the bottom part of the rankings of TMD in both years is Portugal, which changed position in 2019 only by one place compared to 2013. Moreover, Croatia and Bulgaria closed the STMD rankings in 2013 and 2019, respectively.

Based on the TMD values, the most positive change in the ranking over the years 2013–2019 was noted for Malta and Estonia (shifting by six places). In Malta, the main causes of the great improvement were significant increases in the population's attained in tertiary education (variable X_6) and share of the households with high-speed Internet access (X_8). In Estonia, a decrease in air-emission intensity from industry (X_5) and an increase in patent applications to the European Patent Office (X_3) mainly improves the level of SDG 9. On the other hand, the most negative change was noted for Latvia (shifting by ten places). It was caused by a significant decrease in values of the variable X_3.

Comparing rankings created based on the TMD and STMD values, Greece is the country with the most negative differences observed. That was the

Table 2. Values of the coefficient of variation and spatial autocorrelation test for diagnostic variables

Characteristic	Variable							
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
V	52.31%	41.61%	130.37%	25.59%	128.86%	20.98%	40.19%	73.86%
Moran test								
***I* statistics**	0.3910	0.5105	0.3572	0.1069	0.0697	0.1900	0.0449	0.2731
p-value	0.0000	0.0000	0.0000	0.0040	0.0372	0.0000	0.1174	0.0000

Source: own elaboration

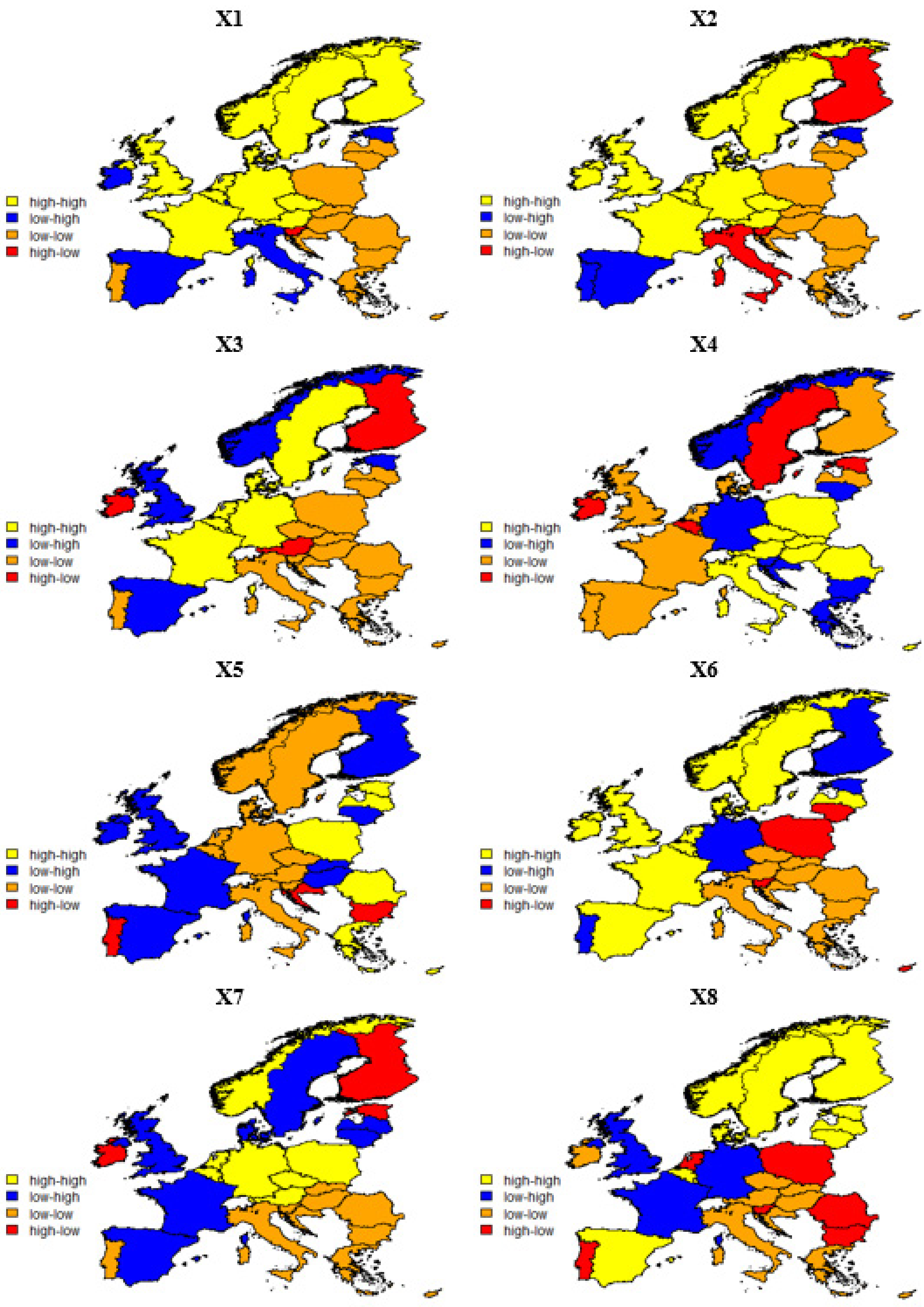

Fig. 1. Spatial distributions of all diagnostic variables

result of the presence of Romania, Bulgaria and Cyprus among neighboring countries. These three countries had a very low level of TMD, which affected the STMD values for Greece. The most positive difference in rankings concerned Spain and Finland. The former shifted from 22nd position in the TMD ranking to 5th in 2013 and 8th in 2019, respectively. This derived from its neighborhood with France and the Netherlands, which scored a high level of the considered process. In turn,

Table 3. Values of TMD and STMD for selected European countries in the years 2013 and 2019 with positions in rankings

Country	Year							
	2013				2019			
	TMD	Rank	STMD	Rank	TMD	Rank	STMD	Rank
Sweden	0.4431	1	0.4533	2	0.5197	1	0.5542	2
Denmark	0.4429	2	0.4698	1	0.5126	2	0.5665	1
France	0.3311	3	0.3223	4	0.3997	5	0.4459	5
Greece	0.2875	4	0.0518	27	0.3447	8	0.1675	27
Netherlands	0.2863	5	0.2993	7	0.4111	3	0.4604	4
Belgium	0.2585	6	0.3070	6	0.4104	4	0.4941	3
Austria	0.2429	7	0.1963	12	0.3795	6	0.3961	9
Luxembourg	0.2360	8	0.1960	13	0.3580	7	0.3686	11
Ireland	0.2306	9	0.2447	9	0.3129	9	0.4032	7
Slovenia	0.2228	10	0.1717	15	0.2681	12	0.2807	16
Hungary	0.2090	11	0.1659	17	0.2550	13	0.2678	17
Finland	0.2047	12	0.3228	3	0.2521	14	0.4195	6
Germany	0.1989	13	0.2184	10	0.3050	10	0.3954	10
Norway	0.1804	14	0.2492	8	0.2695	11	0.3507	12
Czechia	0.1787	15	0.1715	16	0.2437	15	0.2987	14
United Kingdom	0.1622	16	0.2030	11	0.2026	20	0.3126	13
Latvia	0.1462	17	0.1954	14	0.1295	27	0.2028	25
Slovakia	0.1346	18	0.1159	21	0.2304	16	0.2657	19
Italy	0.1263	19	0.1104	22	0.1932	21	0.2406	21
Poland	0.1180	20	0.1434	19	0.2293	17	0.2639	20
Lithuania	0.1165	21	0.1447	18	0.1543	25	0.2061	24
Spain	0.1084	22	0.3076	5	0.1668	22	0.4008	8
Cyprus	0.1072	23	0.0712	23	0.1582	23	0.1710	26
Malta	0.0999	24	0.0701	24	0.2241	18	0.2662	18
Estonia	0.0904	25	0.1196	20	0.2116	19	0.2984	15
Romania	0.0897	26	0.0606	25	0.1107	29	0.1451	28
Bulgaria	0.0749	27	0.0364	28	0.1370	26	0.1378	29
Croatia	0.0309	28	0.0301	29	0.1565	24	0.2080	23
Portugal	0.0119	29	0.0571	26	0.1251	28	0.2084	22

Source: own elaboration

Finland moved from 12th position to 3rd in 2013 and from 14th to 6th in 2019. It can be presumed that this situation was the result of Sweden and Denmark, which were located much higher than Finland in the classical TMD ranking. For the other countries, changes between ranks are slight. The lack of meaningful differences in rankings created based on the TMD and STMD values was confirmed by the statistically significant Kendall's τ coefficients presented in Table 4. Values of the Kendall Rank Correlation Coefficient indicated high concordance of compared ranks.

Figures 2 and 3 present the spatial distribution of the TMD and STMD values, respectively. In both figures, the divisions based on the values of measures calculated for 2013 (in part a) and for 2019 (in part b) were shown. Countries were grouped into four collections. Groups were created on the basis of positional measures values of the descriptive statistics. In both figures, a certain

Table 4. The results of rankings concordance test – Kendall's τ

Characteristic	TMD ranking vs. STMD ranking	
	2013	**2019**
Kendall's τ	0.8570	0.8980
p-value	0.0108	0.0061

Source: own elaboration

tendency was observed. In 2013 and 2019, the northern and central parts of the considered area were dominated by countries with high and very high taxonomic measures values. Countries located in Eastern Europe and most of the Southern European nations were characterized by the lowest level of the considered process.

As Table 3 shows, values of taxonomic measures were higher in 2019 than in 2013. In the next part of the analysis, the time tendency of changes in the values of the calculated measures was investigated. Figure 4 presents the formation of the average values of the TMD and STMD in 2013–2019. In every year of the study (except 2013), the TMD and STMD values were higher than the year before. Consequently, an increasing tendency was observed to form both measure values.

To confirm this presumption, trend models given as (5) and (6) were considered. The results of the estimation and verification of these models are reported in Table 5.

Parameters α_1 and β_1 are statistically significant (p-value is less than the adopted significance level – 0.05). Therefore, a particular time tendency in the

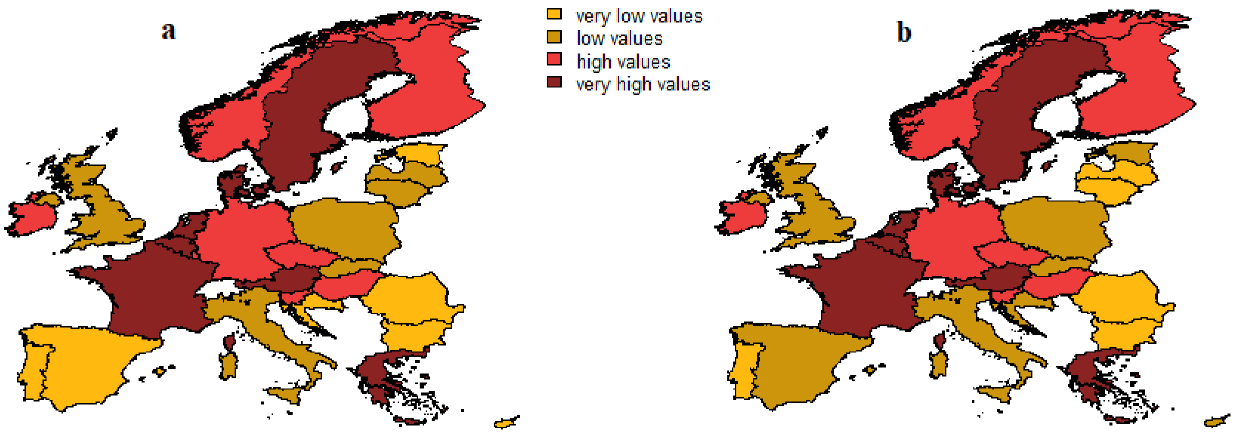

Fig. 2. Spatial distribution of TMD values in 2013 (a) and 2019 (b)

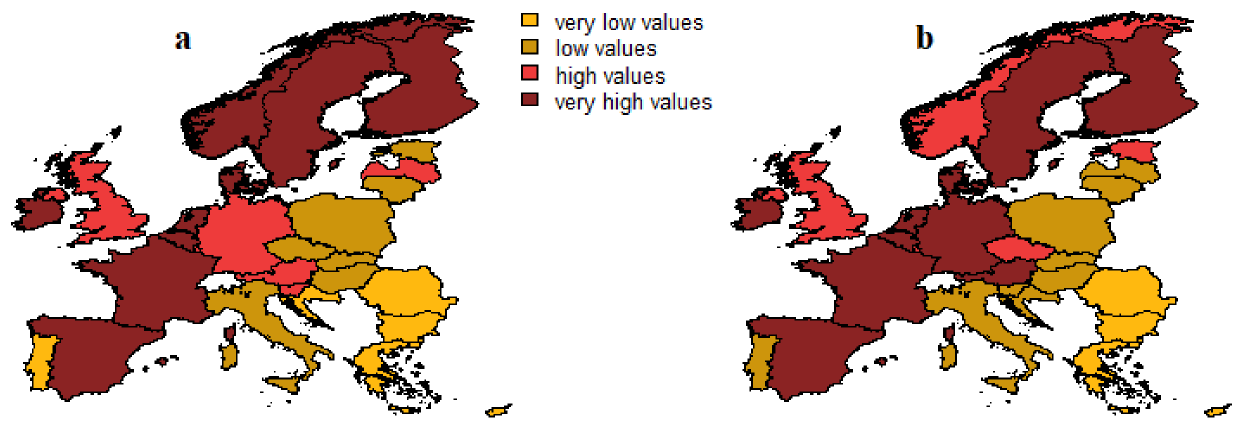

Fig. 3. Spatial distribution of STMD values in 2013 (a) and 2019 (b)

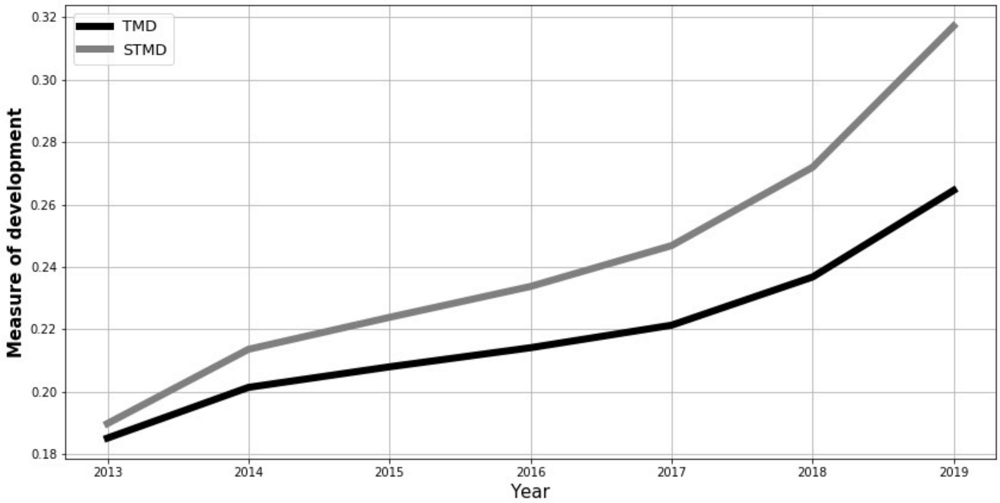

Fig. 4. Formation of the average values of the TMD and STMD in 2013–2019

formation of the average taxonomic measures levels in 2013–2019 was observed. A positive sign of the estimate of parameters α_1 and β_1 denotes that it was an increasing tendency. Based on these results, it can be concluded that, in the selected European countries, the level of SDG 9 improved in the considered period.

5. Discussion and conclusion

The analysis showed that the examined countries are diversified in terms of their performance in SDG 9. The research allowed us to answer Q.1 and Q.2 on the performance and the existence of spatial dependencies in the EU countries in SDG 9 in 2013–19. In general, the northern and central parts of European countries were characterized by high and very high values of SDG 9. At the same time, eastern and most southern European countries formed a group of economies with the lowest level of SDG 9 in 2013 and 2019. The best-performing countries were Sweden and Denmark in 2013 and 2019. In contrast, Portugal was the worst-performing country in 2013, and in 2019 Portugal was also in the group of countries lagging behind. Malta and Estonia experienced the most significant improvement in SDG 9, since they managed to advance their position by six places in the ranking from TMD values.

One of the reasons for such a spatial distribution at the level of SDG 9 is the wealth of economies, as the richer the country is, the better conditions it creates for industry and infrastructure, thus resulting in more innovation. Another reason is that the western and northern parts of Europe are mainly the countries that joined the EU at very early stages of development. This may be connected with better functioning of institutions, quality of governance, ease of doing business, entrepreneurship culture, innovation ecosystems, social and human capital, infrastructural projects, and more.

Table 5. Results of estimation and verification of time trend models for TMD and STMD measures

Parameter	Estimate	Std. Error	t-Statistic	p-value
TMD				
$\boldsymbol{\alpha_1}$	0.0115	0.0007	17.3200	0.0000
STMD				
$\boldsymbol{\beta_1}$	0.0186	0.0008	23.8500	0.0000

Source: own elaboration

When comparing TMD and STMD values rankings, Greece recorded the most negative differences due to having three neighboring countries with low values of SDG 9, namely: Romania, Bulgaria and Cyprus. The most remarkable positive differences were noted for Spain and Finland. Spain moved from 22nd position in the TMD ranking to 5th in 2013 and 8th in 2019, respectively, which may derive from its neighborhood with France and the Netherlands, which were characterized by a high level of the considered process. Finland shifted from 12th to 3rd place in 2013 and from 14th to 6th in 2019, which may have been caused by the impact of Sweden and Denmark, which were the leaders in SDG 9. This allows us to note that the research hypothesis was partially confirmed since, for countries like Spain, Finland or Greece, geolocation matters, but in general, it was not the main factor responsible for the distribution of values of SDG 9 (changes in TMD and STMD were not that major).

The analysis of time tendency changes in SDG 9 showed an increasing trend, so the values increased in time. This means that the level of sustainable industry, infrastructure and innovation increased over the period 2013–2019.

Hence, this study offers some valuable insights for policymakers. It underlines the importance of SDG 9 measures and calls for the need to tailor the policy to specific characteristics of different countries. It is clear that there are differences among countries in SDG 9 performance. However, analyzing the results of this study, some countries should pay more attention to strengthening their performance in SDG 9 measures in order to catch up with others and be more competitive. Since this study proves that geolocation matters – as noted in some positive examples in ranking changes, it is clear that regional development should be enhanced. The EU should address some specific instruments to strengthen and deepen integration across countries, taking some target action, e.g., cross-border cooperation, interreg programs, etc. There are already different initiatives and programs, but they should be more focused on meeting specific goals, such as improving the SDG 9 performance – especially for counties that noted a drop in ranking over time.

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