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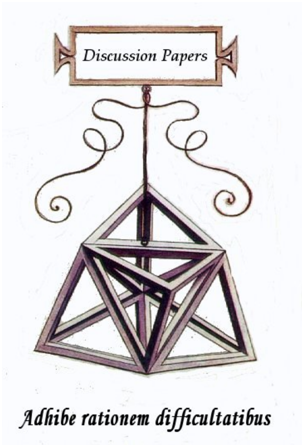

Mateusz Jankiewicz

The analysis of interconnections between the three dimensions of Sustainable Development in terms of the economy structure transformations

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Authors' address/Indirizzo degli autori:

Mateusz Jankiewicz — Nicolaus Copernicus University - Department of Applied Informatics and Mathematics in Economics, Gagarina 13a, 87-100 Toruń - Poland. E-mail: m.jankiewicz@umk.pl

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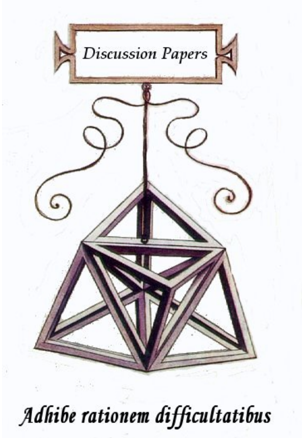

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Abstract

The paper aims to show the analysis of dependencies between the three pillars of Sustainable Development (SD) across the European Union in terms of economy transformation. The provision of simultaneous development in environmental, social and economic dimensions is the crucial task for economies nowadays. Particularly, the highly pointed out negative relation between ecological and environmental development should be neutralised. The study is based on data characterising the European Union countries from 2015 to 2022. Firstly, the level of sustainability achievement in each individual dimension is assessed. For environmental and social sustainability the composite indicator measures are defined and calculated. Economic sustainability is assessed with the Gross Domestic Product per capita level. To detect the occurring connections between SD pillars, the spatial Vector Autoregressive (spVAR) model is estimated and verified. The spatial dependence is included in the system due to the occurrence of spatial autocorrelation in sustainability achievement across the EU. Moreover, to investigate potential effects of the economy modifications in the sustainability achievement, the variables characterising the servitisation and industrialisation levels are additionally employed. The main results show that there is still a negative link between environmental and economic development. Moreover, the supporting role of the progressing servitisation process in sustainability achievement in the environmental and economic dimensions is concluded.

Keywords: economic transformation; spatial dependence; sustainable development; Vector Autoregressive model

JEL CLassification: C51, O14, Q56

The analysis of interconnections between the three dimensions of Sustainable Development in terms of the economy structure transformations

Mateusz Jankiewicz[1]

[1]Nicolaus Copernicus University in Torun, The Department of Applied Informatics and Mathematics in Economics, Jurija Gagarina 13a, 87-100 Torun (Poland), Email: m.jankiewicz@umk.pl

Abstract. The paper aims to show the analysis of dependencies between the three pillars of Sustainable Development (SD) across the European Union in terms of economy transformation. The provision of simultaneous development in environmental, social and economic dimensions is the crucial task for economies nowadays. Particularly, the highly pointed out negative relation between ecological and environmental development should be neutralised. The study is based on data characterising the European Union countries from 2015 to 2022. Firstly, the level of sustainability achievement in each individual dimension is assessed. For environmental and social sustainability the composite indicator measures are defined and calculated. Economic sustainability is assessed with the Gross Domestic Product per capita level. To detect the occurring connections between SD pillars, the spatial Vector Autoregressive (spVAR) model is estimated and verified. The spatial dependence is included in the system due to the occurrence of spatial autocorrelation in sustainability achievement across the EU. Moreover, to investigate potential effects of the economy modifications in the sustainability achievement, the variables characterising the servitisation and industrialisation levels are additionally employed. The main results show that there is still a negative link between environmental and economic development. Moreover, the supporting role of the progressing servitisation process in sustainability achievement in the environmental and economic dimensions is concluded.

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1. Introduction

Sustainable Development (SD) is the crucial issue that governments have to manage nowadays. The "Report of the World Commission on Environment and Development: Our Common Future" (WCED, 1987) paid attention to the growing environmental destruction due to progressing economic growth. Hence, the SD idea was initiated. The report mentioned above quotes one of the most important definitions of SD. There we can find that Sustainable Development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, p. 37). This definition highlights the limitation of natural resources and points out the necessity of their reasonable use. The definition cited does not directly present the relationship between economic, social, and environmental situations. These aspects were revealed and linked during the Earth Summit in Rio de Janeiro in 1992. The approach considering common development in these three dimensions is highlighted in strategic documents of the European Union these days.

The Triple Bottom Line (TBL) concept was created based on justice among the economic, environmental, and social pillars, which is its most important postulate (Elkington, 1997). The natural, social, and human conditions, which are very important for income and living standards, require economic sustainability. Moreover, social sustainability provides human rights and equality and also secures the cultural dimension of life. In turn, the maintenance of the quality of the environment and the quantity of natural resources is a task for environmental sustainability. The quality of the environment and quantity of natural resources support the quality of life and help achieve desirable economic goals. The difficulty of attaining justice among the three pillars of SD is widely underlined in the literature. The focus on development in one aspect often leads to crashes in the others, making them unsustainable. Therefore, balancing all aspects of SD should be considered when making decisions about the improvement of one pillar (Klarin, 2018). The TBL concept focuses on achieving sustainable development in a broader sense than the Sustainable Development Goals (SDGs) idea, for example, where 17 particular goals are established in the 2030 Agenda for Sustainable Development. Nevertheless, the 2030 Agenda points out that the SDGs balance the three dimensions of SD: economic, social, and environmental (2030 Agenda for Sustainable Development, p. 3).

The development of countries causes the progressing change in the economic structure concerning the modifications in its three crucial sectors: services, industry, and agriculture (Abdullajanovich, 2022; Han et al., 2020). The changes mentioned above are visible in the structure of value added in Gross Domestic Product (GDP) coming from these three sectors separately. Mainly, economies follow the direction of servitisation. Above all, the transformation of the production process towards increasing the use of services by manufacturers causes the presented modifications. This tendency is observed in developed countries (Opresnik & Taisch, 2015). In the literature, the progressing servitisation due to an increasing development level is underlined (Friesenbichler & Kügler, 2022). Changes in the economic structure are relevantly connected with the achievement of sustainable development. The desirable influence of servitisation, digitalisation, and digital servitisation on the environmental and social dimensions of SD is pointed out (Jankiewicz, 2024a; Xie et al., 2023; Hojnik, 2018). In turn, the industrialisation process is usually presented as a process causing environmental degradation (Sarkodie et al. 2020; Bian et al. 2019). Agricultural development is considered a driver of sustainable development in developing countries (Pata, 2021).

The mutual relations of countries are very important in the creation of their development nowadays. Hence, in the analyses of sustainable development, the inclusion of the spatial aspect is significant (Shaker, 2015). The free movement of human capital and knowledge causes cooperation between countries to become more and more crucial (Zamani & Tayebi, 2022).

This research aims to investigate the relationship between the three dimensions of sustainable development across European Union (EU) countries in the years 2015-2022. Firstly, the achievement of sustainability in particular dimensions is assessed, while the social and environmental pillars are treated as multidimensional phenomena, and composite indicators are used to calculate their level. The analysis is conducted in terms of changes in economic structure, so the phenomena concerning the industrialisation and servitisation processes are included in the study. The rising relevance of cooperation between countries has caused the inclusion of the spatial factor in the research. The spatial dependence in the investigation is included in the form of a spatial connection matrix built based on the common land border criterion. In the empirical analysis, the Vector Autoregression (VAR) model with the spatial dependence factors is estimated and verified. The research aims to answer the following questions: (1) Does the focus on economic sustainability harm environmental development and vice versa? (2) Is the sustainability of economic and environmental dimensions a driver of social sustainability? (3) Does the economic transformation towards servitisation support all three pillars of SD? (4) Are the spatial dependencies significant in the analysis of interconnections between SD pillars?

2. Literature review

The crucial aspect of this research is to analyse interdependencies between environmental, social, and economic development in the light of sustainable development. Some researchers have focused on this topic so far. Ghimire (2023) pointed out the challenges and achievements in the case of all three SD pillars, highlighting simultaneously the worst situation of environmental development. In the research, she concluded that there is a negative trend in resource depletion, habitat destruction, and climate change. She pointed out the reduction of poverty as the most important factor in achieving social sustainability. As an advantage, Ghimire recognised green technologies and responsible supply chains that positively influence economic sustainability. Thus, the dissonance between ecological and economic situations is exposed. Singh et al. (2021) analysed the influence of all pillars on sustainable development in selected economies. They calculated sustainability in each sector and sustainability as a whole using a composite Z-score approach. Then they estimated linear and non-linear models of the relationship between the global sustainable development index and the indices mentioned above. They concluded that there is a positive and significant link between SD and all three pillars. This means that all factors are relevant to achieving sustainability. Additionally, they included the deforestation factor in the models, which showed its negative influence on SD. Their correlation of indices analysis presents that all three pillars are positively correlated, but the environmental and economic factors are the least so. Perrings and Ansuategi (2000), in one of the first studies on the interconnections between ecological, social, and economic situations, indicate the link between poor environmental situations and social conditions. As an example, they cited poor health resulting from a shortage of clean water. On the other hand, they underlined that increasing wealth harms the environmental situation due to overconsumption. Based on these connections, they presented the negative relation between economic and ecological sections and a common path for environmental and social situations. Singh et al. (2019) concluded similar relations between environmental and socio-economic indicators by analysing them across selected Asian economies. They built the environmental situation index as a composite measure, but for the economic and social standards indicators, they used Gross Domestic Product (GDP) per capita and Human Development Index (HDI), respectively. Slightly different results were presented by Hysa et al. (2020). They obtained a positive correlation between environmental situation and economic growth by analysing it in selected European countries. Nevertheless, the ecological situation was assessed only through the level of environmental tax revenues and the recycling rate of municipal waste. They used these variables as explanatory variables in the log-linear model of GDP per capita. Additionally, they concluded that there was simultaneous growth in social and economic conditions. The interactions between SD pillars included in the 2030 Agenda are also presented in the study carried out by Tremblay et al. (2020).

Most studies concentrate only on the relationship between the environmental and economic pillars. For example, Jahanger et al. (2022) conducted an analysis of 69 developing countries, concluding about the negative impact of the globalisation process on the ecological situation. Moreover, they highlighted the need to turn manufacturing habits towards eco-friendly technologies. Ahmad et al. (2020) also conducted research on selected developing economies regarding the linkage between ecology and economy. They concluded that there exists an inverted U-shaped link between carbon dioxide (CO_2) emissions and GDP per capita, which confirms the environmental degradation resulting from economic development in developing countries. Tenaw and Beyene (2021) applied the same method to investigate the connection mentioned above across sub-Saharan African countries. Nevertheless, instead of GDP per capita, they considered the HDI measure. They also proved that maintaining environmental sustainability at the early stages of socio-economic development is difficult to achieve. In turn, Arslan (2022) showed that natural resources improve the environmental situation. However, in the long run, natural resources slow down the economic development of states. They presented this relationship based on data related to China. Other studies present the negative relationship between economic and environmental development in South Asia (Murshed et al., 2021) and India (Orhan et al., 2021).

The formation of sustainable development is taking place in terms of economic structure modifications that also have a significant impact on it. Luo and Liu (2024) presented that the servitisation process through digital transformation supports sustainable development, particularly in the environmental and economic sectors. According to their research, digitalisation improves the sustainability of resource-based enterprises and technology-intensive enterprises, which translates to the sustainability of the whole economy. The next researcher who concluded about the positive impact of the servitisation process on environmental sustainability is Corrêa (2018). Savona and Ciarli (2019), based on the analysis across selected OECD countries, concluded that the modifications towards greater use of services cause the dematerialisation of economies and reduction of energy intensity. They highlighted that this transformation is favourable for the ecological situation. Brenner and Hartl (2021) considered the impact of the servitisation process on all three SD pillars. The general conclusion from their research is that the focus on services improves sustainability in all sectors, but most significantly in the social aspect. The potential for achieving sustainability through servitisation is also presented in research conducted by Seele and Lock (2017). Moreover, Menon et al. (2024), based on a wide literature review, pointed out that economic and environmental sustainability is an important benefit of the servitisation process. Other researchers pointed out the desirable results of exploring services for SD, conducted by Bressanelli et al. (2024) and Johl et al. (2024). Abdelkafi et al. (2022), despite the positive aspects, indicate some negative consequences of servitisation for sustainable development. Moreover, Jankiewicz (2024a) concluded about the positive impact of the economic transformation structure through servitisation on social sustainability across selected developing economies.

In turn, another study shows the influence of the industrialisation process on sustainable development, particularly its ecological aspect. Nasrollahi et al. (2020), based on the STRIPAT model results, concluded about the detrimental effect of the industrial sector's expansion on the environmental situation in MENA and OECD countries. Rasheed et al. (2024) indicated the destructive impact of industrialisation on the environmental situation, measured by the carbon footprint indicator in selected Asian economies. Also, Wang et al. (2022) concluded about the degradation of the natural environment, this time according to G-7 countries. They additionally included the renewable energy and trade openness factors in models as processes that relevantly affected this sector of SD. Models estimated by Saba et al. (2024) and Hussain and Zhou (2022) also presented the destructive impact of industrialisation on the natural environment, increasing CO_2 emissions levels. In turn, Fang (2023) concluded about the decreasing negative impact of industrialisation on the environmental situation in China. Nevertheless, he underlined the need for a focus on the green technology expansion to strengthen sustainability. On the other hand, Hemakumara and Dissanayake (2020) showed industrialisation as a positive cause for achieving environmental sustainability in Sri Lanka. In turn, Alcorta (2015) highlighted the significance of industry expansion for economic and social sustainability through employment and, as a result, the reduction of poverty. Some studies show the linkage between the considered processes in the case of African countries. Nulambeh and Jaiyeoba (2024) concluded the destructive effect of industrialisation on the environmental situation across sub-Saharan economies. They obtained a positive relation between the share of employment in the industrial sector and ecological footprint, which confirms the negative impact of industrialisation on environmental sustainability. The same character of the investigated relationship was shown in the study conducted by Saba et al. (2023) and Aquilas et al. (2024). They asked the question of how to make the industry sustainable in Africa to avoid destructing the natural environment in terms of its expansion.

Few studies concentrate on the spatial aspect in measuring sustainable development and analysing the relationship between its particular pillars. Chai et al. (2021) estimated spatial models to detect the relation between economic targets and environmental sustainability in China. They concluded about the occurrence of significant spatial spillovers and a negative relation between economic growth and the ecological situation. In turn, Luo et al. (2023) applied spatial econometric tools in the analysis of the dependence between the digitalisation process and the achievement of sustainable development through green innovations. They pointed out that the digitalisation process promotes green innovations. The green growth in terms of spatial dependence was under consideration in the study conducted by Cai et al. (2022) and Li et al. (2023). Other studies used spatial models in the sustainable development analysis across BRICS countries (Wahab et al., 2022), Southeast Asia (Fong et al., 2020), US urban areas (Buck et al., 2021), and European Union countries (Jankiewicz & Szulc, 2024; Kwilinski et al., 2023).

Nevertheless, none of the studies mentioned above employ spatial econometric models in the analysis of the relationship between individual pillars of sustainable development. Given the lack of studies analysing the interconnections between all three pillars of sustainable development, particularly applying the spatial dependence of territorial units, this paper constitutes significant added value to the literature.

3. Methods and data

The first stage of the analysis is to evaluate the level of sustainable development achievement in three pillars (environmental, social and economic) separately. The environmental and social sustainability are considered in this study as multi-featured phenomena, therefore the composite indicator calculation is needed to assess their level. The economic sustainability is assessed with the values of Gross Domestic Product per capita.

At the starting point of calculation of composite indicator, the matrix of initial diagnostic variables (which significantly impact considered phenomenon) is created. Next, the construction of the TMD is carried out according to the following scheme (Hellwig, 1968; Kuc-Czarnecka et al., 2020; Jankiewicz 2024b):

i. Determination of the final set of diagnostic variables. In this step, the quasi-constant variables are omitted and variables highly correlated with at least one of the remaining determinants. As a result, variables significantly differentiate territorial units, and the information carried by the variables is not duplicated.
ii. Normalization of variable values to enable comparability. In this research, the following unitarization formula is used:

$$x'_{ji,t} = \frac{x_{ji,t} - \min x_{ji,t}}{\max x_{ji,t} - \min x_{ji,t}}, \tag{1}$$

where $x'_{ij,t}$ expresses the normalized value of the variable, $x_{ji,t}$ is the value of j^{th} variable x in i^{th} country in time t, $\min x_{ji,t}$ and $\max x_{ji,t}$ denote the minimum and the maximum values of j^{th} variable, respectively. The purpose of this step is to avoid the influence of differences resulting from the measurement units of the features.

iii. Establishment of the character of variables. At this stage, variables are shared into stimulants and variables with opposite effect to stimulants (called destimulants). Stimulants affect the phenomenon positively, and their high values are desirable, opposite to destimulants.
iv. Determination of the pattern of development ($\bar{z}$) – a vector of desirable values of variables set out as:

$$\bar{z} = [z_{01}, z_{02}, \ldots, z_{0n}], \tag{2}$$

whereas

$$z_{0j} = \begin{cases} \min_j x'_{ji,t} : & x_j \in D \\ \max_j x'_{ji,t} : & x_j \in S \end{cases}, \tag{3}$$

where D and S are sets of destimulants and stimulants, respectively, and n denotes the number of variables ($j = 1, 2, \ldots, n$). The pattern of development is the object to which the situation in every territorial unit speculated in the research is compared. This is the best possible situation resulting from the available dataset.

v. Evaluation of distances to pattern for each country in every year of the research using the Euclidean distance. A greater distance from the pattern means a worse situation in a given object.
vi. Normalization of the distance measure with the expression:

$$CI_{i,t} = 1 - \frac{d_{i0}}{d_0}, \tag{4}$$

where d_{i0} is the distance between i^{th} country in time t and pattern of development, whereas d_0 is the norm of the distances d_{i0} expressed as its arithmetic average plus twice the standard deviation. Normalization of the composite indicator causes the CI to be in the range between 0 and 1. Higher values of CI signalize a better situation for development in the particular dimension.

Next, the occurrence of global spatial autocorrelation for calculated SD measures is checked. This type of autocorrelation refers to dependence between neighbouring regions. Moran's I statistics is used the most often to test the spatial autocorrelation and takes the following form (Moran, 1948; Schabenberger and Gotway, 2005):

$$I = \frac{1}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \cdot \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\,[y_i - \bar{y}][y_j - \bar{y}]}{\frac{1}{n}\sum_{i=1}^{n}[y_i - \bar{y}]^2} = \frac{n}{S_0} \cdot \frac{\boldsymbol{z}^T \boldsymbol{W} \boldsymbol{z}}{\boldsymbol{z}^T \boldsymbol{z}}, \quad (5)$$

where y_i is the observation of the process in the ith region, $\bar{y}$ denotes the average value of the process, and $\boldsymbol{W}$ is the matrix of spatial connections between units. In this research, the row-standardized to unity matrix based on the common border criterion (marked as $\boldsymbol{W}$) is uses. There are islands in the group of territorial units studied and they do not have any neighbour in the light of the chosen proximity criterion. Therefore, the spatial lag of variables for these particular countries is equal to zero. Statistically significant Moran's I coefficient signalizes the presence of spatial autocorrelation.

After checking the spatial autocorrelation occurrence, the relationship between all sustainable development pillars is considered estimating the spatial Vector Autoregression (SpVAR) model in following form:

$$\begin{aligned} Y_{i,t}^{j} = \beta_0^j + \alpha_1^j \ln(ECI)_{i,t-1} + \alpha_2^j \ln(SCI)_{i,t-1} + \alpha_3^j \ln(GDP)_{i,t-1} + \\ +\beta_1^j t + \beta_2^j \ln(IVA)_{i,t} + \beta_3^j \ln(SVA)_{i,t} + \gamma_1^j \boldsymbol{W}^* \ln(IVA)_{i,t} + \\ +\gamma_2^j \boldsymbol{W}^* \ln(SVA)_{i,t} + \gamma_3^j \boldsymbol{W}^* \ln(ECI)_{i,t} + \gamma_4^j \boldsymbol{W}^* \ln(SCI)_{i,t} + \\ +\boldsymbol{W}^* \gamma_5^j \ln(GDP)_{i,t} + \varepsilon_{i,t}^{j}, \end{aligned} \quad (6)$$

where $Y_{i,t}^{j}$ denotes the explained variable (sustainability in the particular dimension) in jth equation ($j \in \{1,2,3\}$) in time t, ln $(ECI)_{i,t-1}$ and ln $(SCI)_{i,t-1}$ are lagged natural logarithms of environmental and social sustainability indicators, respectively. Moreover $\ln(GDP)_{i,t-1}$ denotes the lag of natural logarithm of Gross Domestic Product per capita, ln $(IVA)_{i,t}$ and ln $(SVA)_{i,t}$ are the shares of value added in GDP per capita coming from industry and services, $\boldsymbol{W}^*$ln $(ECI)_{i,t}$, $\boldsymbol{W}^*$ln $(SCI)_{i,t}$, $\boldsymbol{W}^*$ln $(GDP)_{i,t}$, $\boldsymbol{W}^*$ln $(IVA)_{i,t}$ and $\boldsymbol{W}^*$ln $(SVA)_{i,t}$ indicate the average value of variables in neighbouring countries, wherein $\boldsymbol{W}^*$ is the block matrix of spatio-temporal connections which takes the form (Szulc & Jankiewicz, 2018):

$$\boldsymbol{W}^* = \begin{bmatrix} \boldsymbol{W}_1 & \cdots & \boldsymbol{0} \\ \vdots & \ddots & \vdots \\ \boldsymbol{0} & \cdots & \boldsymbol{W}_T \end{bmatrix}, \quad (7)$$

wherein: $\boldsymbol{W}_1 = \cdots = \boldsymbol{W}_T$ represent standard spatial connectivity matrices (the same for all years). Moreover, t denotes the time variable. In turn, α_1^j, α_2^j, α_3^j, β_0^j, β_1^j, β_2^j, β_3^j, γ_1^j, γ_2^j, γ_3^j, γ_4^j, γ_5^j, ρ^1, ρ^2, ρ^3 are the structural parameters, and $\varepsilon_{i,t}^j$ denote the random components of each equation. The above system is estimated with the generalized method of moments (GMM) due to the time dynamics component. Spatial lags are included in the equations due to the occurrence of spatial autocorrelation in considered phenomena. Despite the occurrence of the spatial lags of the endogenous elements as the explanatory variables, the method of estimation is correct due to employing the lags of endogenous variables as instruments.

Table 1. The list of diagnostic variables for the assessment of SD achievement

Environmental sustainability			
Symbol	**Variable**	**Measure**	**Character**
E1	Ammonia emissions from agriculture	Kilograms per hectare	D
E2	Final energy consumption in households per capita	Kilogram of oil equivalent (KGOE)	D
E3	Share of renewable energy in gross final energy consumption	%	S
E4	Recycling rate of municipal waste	%	S
E5	Raw material consumption (RMC)	Tonnes per capita	D
E6	Consumption footprint – single weighted score	Per inhabitant	D
E7	Circular material use rate	%	S
E8	Net greenhouse gas emissions	Tonnes per capita	D
E9	Share of environmental taxes in total tax revenues	%	D
E10	Share of forest area	%	S
Social sustainability			
S1	Persons at risk of poverty or social exclusion	%	D
S2	Persons at risk of monetary poverty after social transfers	%	D
S3	Severe material and social deprivation rate	%	D
S4	Persons living in households with very low work intensity	%	D
S5	In work at-risk-of-poverty rate	%	D
S6	Housing cost overburden rate	%	D
S7	Agricultural real factor income	euro per annual work unit (AWU)	S
S8	Government support to agricultural research and development	euro per inhabitant	S
S9	Healthy life years at birth	Healthy life years in absolute value at birth	S
S10	Share of people with good or very good perceived health	%	S
S11	Self-reported unmet need for medical examination and care	%	D
S12	Early leavers from education and training	%	D
S13	Tertiary educational attainment	%	S
Economic sustainability			
EC1	Gross Domestic Product	euro per capita	S

Almost all data used in this study come from the European Statistical Office (EUROSTAT) database (https://ec.europa.eu/eurostat/data/database, accessed on: 7.11.2024). Table 1 presents the diagnostic variables with the division on the environmental, social and economic character. Based on the environmental and social variables the composite indicators are calculated. Only the variable characterising the forest area (E10) comes from the Climate Change Indicators Dashboard (https://climatedata.imf.org/, accessed on 28.09.2024). In turn, the shares of value added in GDP coming from industry and services are taken form the World Bank Indicators dataset (https://data.worldbank.org/indicator, accessed on: 28.09.2024). The data in the analysis refer to the European Union countries in period between 2015 and 2022.

4. Empirical results

At the first stage of the analysis, the assessment of Sustainable Development with regard to the three pillars (environmental, social, and economic) is presented. The level of the environmental and social pillars is calculated using the composite indicator. In turn, economic development is evaluated based on the Gross Domestic Product per capita values. Table 2 presents the rankings of countries in the first and the last year of the investigation, sorted decreasingly according to the values of the environmental development measure (ECI) in 2015.

As we can see, Austria takes first place in both rankings of environmental sustainability. In second place in 2015 was Sweden, with the value of ECI equal to 0.4538. Nevertheless, Sweden's fall in the ranking indicates a drop to fourth place in 2022. This was not the result of a deterioration of the ecological situation there, but rather that environmental sustainability improved in the countries immediately behind Sweden, namely France (which kept 3rd place) and Slovenia (which moved up in ranking from 4th to 2nd place). At the bottom of the rankings, there were also few changes between 2015 and 2022; however, the last place, despite the high increase in the ECI measure level (from 0.0231 to 0.1167), belonged to Malta. Overall, the environmental situation improved across the European Union during the analysed period. Only four of the twenty-seven countries indicated a decrease in environmental sustainability achievement. The first is Poland, where the decrease was the least significant, but the fall in ranking was visible (from 11th place to 17th place). Mainly, this is the result of growing raw material consumption (variable E5) and an increasing consumption footprint (variable E6). The next countries are Bulgaria and Finland, where the decrease in the ES measure was around 0.08. In Finland, the circular material use rate fell drastically during the analysed period, and additionally, raw material consumption increased. In Bulgaria, alongside the increase in raw material consumption, the consumption footprint grew as well. In turn, the decrease in the share of renewable energy consumption was the main cause of Romania's environmental sustainability deterioration (the value of the ECI measure went down from 0.2751 to 0.2279) and the collapse in the ranking.

The greatest positive change in the ecological situation across the EU was observed in Slovakia and the Netherlands, where the improvement between rankings from 2015 to 2022 was by 11 and 7 places, respectively (Slovakia from the 17th to the 6th and the Netherlands from the 18th to the 12th place). This situation is mainly the result of the decrease in ammonia emissions levels (variable E1) and the share of renewable energy consumption (variable E3). Additionally, in Slovakia, the biggest increase in the recycling rate of municipal waste (variable E4) was noted.

Table 2. The results of the assessment of sustainable development (values of sustainability pillars measures) in 2015 and 2022 with rankings

Country	Environmental pillar				Social pillar				Economic pillar			
	ECI 2015	Rank	ECI 2022	Rank	SCI 2015	Rank	SCI 2022	Rank	GDP 2015	Rank	GDP 2022	Rank
Austria	0.4551	1	0.5033	1	0.4389	10	0.5215	9	36140	6	38080	6
Sweden	0.4538	2	0.4756	4	0.5749	1	0.6008	5	42170	4	45100	4
France	0.4278	3	0.4764	3	0.5525	4	0.5712	7	31780	10	33540	10
Slovenia	0.4245	4	0.4943	2	0.3940	13	0.5477	8	17820	15	21790	15
Italy	0.4219	5	0.4664	5	0.2524	19	0.3791	20	25960	11	28670	11
Lithuania	0.4001	6	0.4200	10	0.2324	22	0.3311	25	11620	21	15100	21
Spain	0.3836	7	0.4183	11	0.2778	18	0.4482	15	23340	12	25270	14
Portugal	0.3802	8	0.3850	14	0.1804	24	0.3338	24	16620	17	19310	16
Latvia	0.3745	9	0.4512	7	0.1745	25	0.2679	26	10760	25	13220	25
Germany	0.3612	10	0.4219	9	0.4323	12	0.5134	11	34810	7	36690	9
Poland	0.3578	11	0.3533	17	0.3137	16	0.4012	18	10890	23	14670	23
Estonia	0.3375	12	0.4312	8	0.1971	23	0.3430	23	13410	20	16120	20
Hungary	0.3249	13	0.3484	18	0.2802	17	0.3612	21	11220	22	14360	24
Bulgaria	0.3163	14	0.2394	20	0.2425	20	0.3481	22	5700	27	7680	27
Belgium	0.3109	15	0.3874	13	0.4780	8	0.6186	4	34360	8	37050	8
Czechia	0.3058	16	0.3716	16	0.4388	11	0.5151	10	16440	18	18690	17
Slovakia	0.2953	17	0.4641	6	0.3508	15	0.4474	16	14340	19	16360	19
Croatia	0.2946	18	0.3725	15	0.2355	21	0.3850	19	10850	24	14750	22
Netherlands	0.2918	19	0.4088	12	0.5647	2	0.6927	2	39680	5	44870	5
Romania	0.2751	20	0.2279	21	0.0287	27	0.1686	27	7420	26	10030	26
Denmark	0.2542	21	0.3090	19	0.5550	3	0.6005	6	45500	3	51600	3
Finland	0.2481	22	0.1699	26	0.5078	7	0.5050	12	34270	9	37330	7
Greece	0.2091	23	0.2193	22	0.1501	26	0.4107	17	16900	16	18690	17
Cyprus	0.1387	24	0.1764	24	0.5231	5	0.6258	3	21120	13	27480	12
Ireland	0.0766	25	0.1908	23	0.5166	6	0.7560	1	50270	2	77300	2
Luxembourg	0.0613	26	0.1704	25	0.4478	9	0.4614	14	82820	1	85850	1
Malta	0.0231	27	0.1167	27	0.3657	14	0.4637	13	20360	14	25450	13

In the case of social sustainability, Sweden took first place in the ranking in 2015 with the value of the composite measure (SCI) of 0.5749. The next positions were occupied by the Netherlands, Denmark, France, and Cyprus, but the differences in the level of social sustainability were not substantial. Sweden fell in the hierarchy to 5th place despite the increase in the level of social sustainability achievement. This is the result of faster social development in Ireland (1st place in 2022 and an increase in the SCI measure of around 0.24), the Netherlands (keeping 2nd place), Cyprus (moving to 3rd place from 5th), and Belgium (improvement in classification by four places from 8th). The enhancement concerning Ireland was mainly caused by the decrease in the number of persons at risk of monetary poverty after social transfers (variable S2) and the increase in the share of people with good or very good perceived health (variable S10). Moreover, Ireland showed improvement in all the remaining characteristics. In turn, in Belgium, the decrease in the self-reported unmet need for medical examination and care (variable S11) and early leavers from education and training (variable S12) led to a rise in the social composite indicator level of around 0.14. The worst social situation in both 2015 and 2022 was observed in Romania. Meanwhile, Greece showed a jump in the ranking from the second-to-last position in 2015 to 17th in 2022. There, the decrease in the housing cost overburden rate mainly caused the improvement in social sustainability. In almost all countries (excluding Finland), social conditions enhanced. In Finland, the deterioration of the social situation was the result of the increase in the housing cost overburden rate (variable S6) and the decrease in the share of people with good or very good perceived health (variable S10). The next country with the highest drop in ranking is Luxembourg, but in this case, slower social development than in the other countries was decisive. The changes in rankings between 2015 and 2022 concerning the second pillar of SD seem to be less significant than those regarding environmental sustainability.

The top of the rankings for economic development in 2015 and 2022 was the same. The first five places were occupied by Luxembourg, Ireland, Denmark, Sweden, and the Netherlands. Analogously, the last three places (from the 25th to 27th) did not change between 2015 and 2022. The last place belonged to Bulgaria, followed by Romania, which had a higher level of GDP by around 1,400 euros in 2015 and around 2,400 euros in 2022. Moreover, Latvia was placed in the third-to-last position in the rankings in the two extreme years of the investigation. According to the Gross Domestic Product levels, there are no significant changes in the hierarchy, and in all countries, economic development improved.

Crucial for this study is the comparison of the rankings between particular pillars of SD. Table 3 presents the results of the analysis of the rankings compatibility test using the Kendall W statistics. The most substantial similarity we can note when comparing orders concerning social and economic sustainability measures is that the W statistic is almost 0.9, with the test probability below the given significance level of 0.05. On the other hand, the rankings based on the environmental sustainability measure in both years significantly differ from the rankings of countries created for the remaining pillars of SD. The values of the W statistics do not exceed 0.5, which indicates a little compatibility of orders.

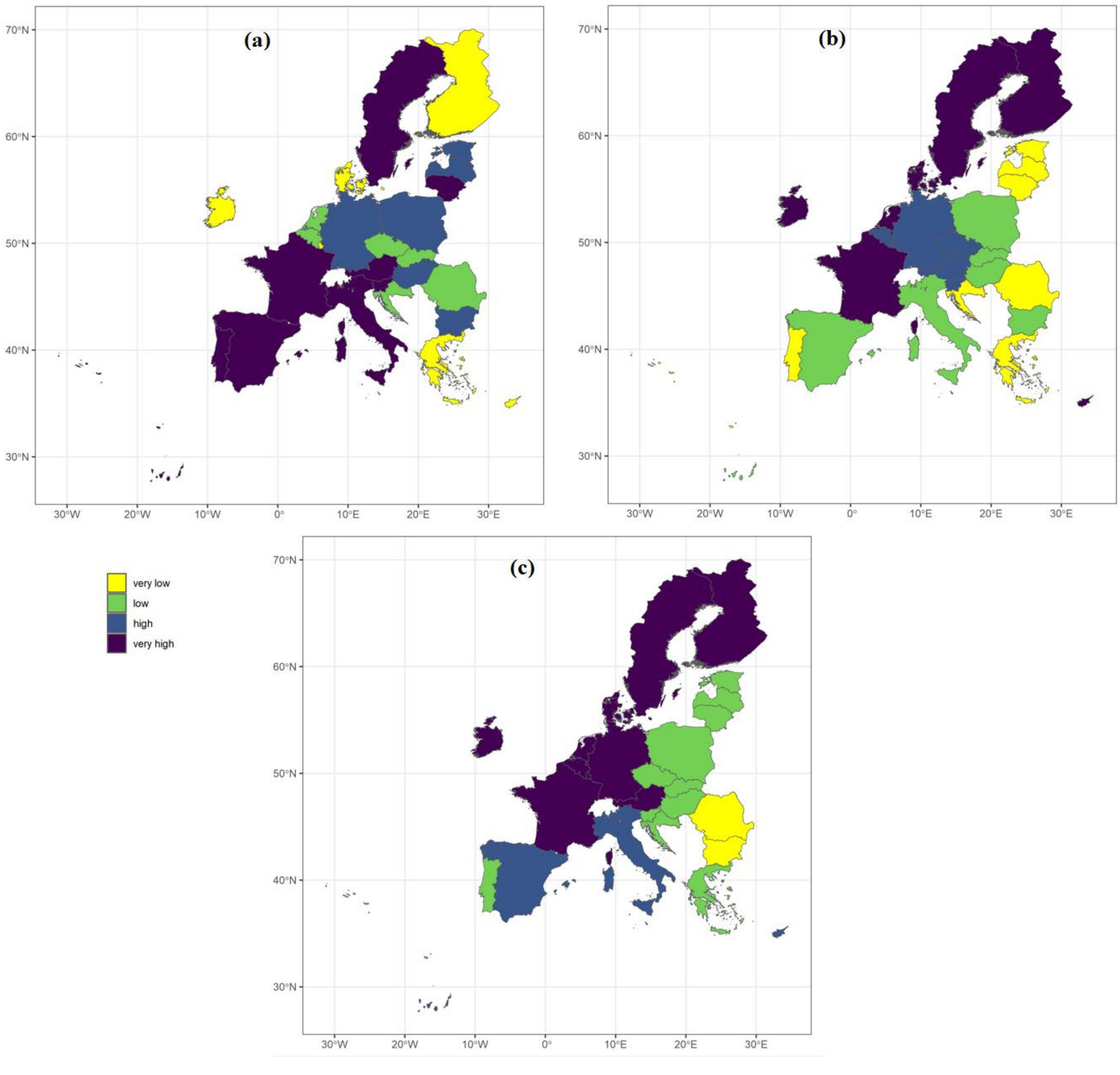
Table 3. The results of the rankings compatibility test

Year	**ENV vs. SOC**	**ENV vs. ECO**	**SOC vs. ECO**
2015	W = 0.4480 (0.6150)	W = 0.4510 (0.6090)	W = 0.8930 (0.0082)
2022	W = 0.4940 (0.4810)	W = 0.4980 (0.4680)	W = 0.8950 (0.0080)

Note: Numbers in brackets indicate p-value of Kendall statistics significance.

To present the legitimacy of the spatial dependencies introduced in further analysis, the spatial differentiation of the sustainability measures and the spatial autoregression occurrence test should be added. Figure 1 presents the spatial differentiations of the level of sustainability achievement in all pillars in 2015. Part (a) contains the map with the diffusion of values of environmental sustainability. As it can be seen, most countries with very high values of the measure of ecological situation are located in the south-west part of the EU. Additionally, in this group, Sweden and Lithuania are included. In turn, states with the poorest environmental situation are not clustered in a common part of the continent. The central part of the EU varies in terms of environmental sustainability achievement. Part (b) of Figure 1 presents the spatial differentiation of the social sustainability measure. There, the southern and eastern parts of the considered area are dominated by countries with low and very low social sustainability situations. It can be seen that the EU is divided into two separate clusters. The first group, with higher values of the considered measure, is located in the north and west. The GDP per capita values show a similar spatial distribution—see part (c) of Figure 1. Almost all countries situated in the northern and western EU area (excluding Portugal) belong to two groups with GDP per capita values above the median. The division into separate clusters regarding economic development is more visible than in the case of the achievement of social sustainability.

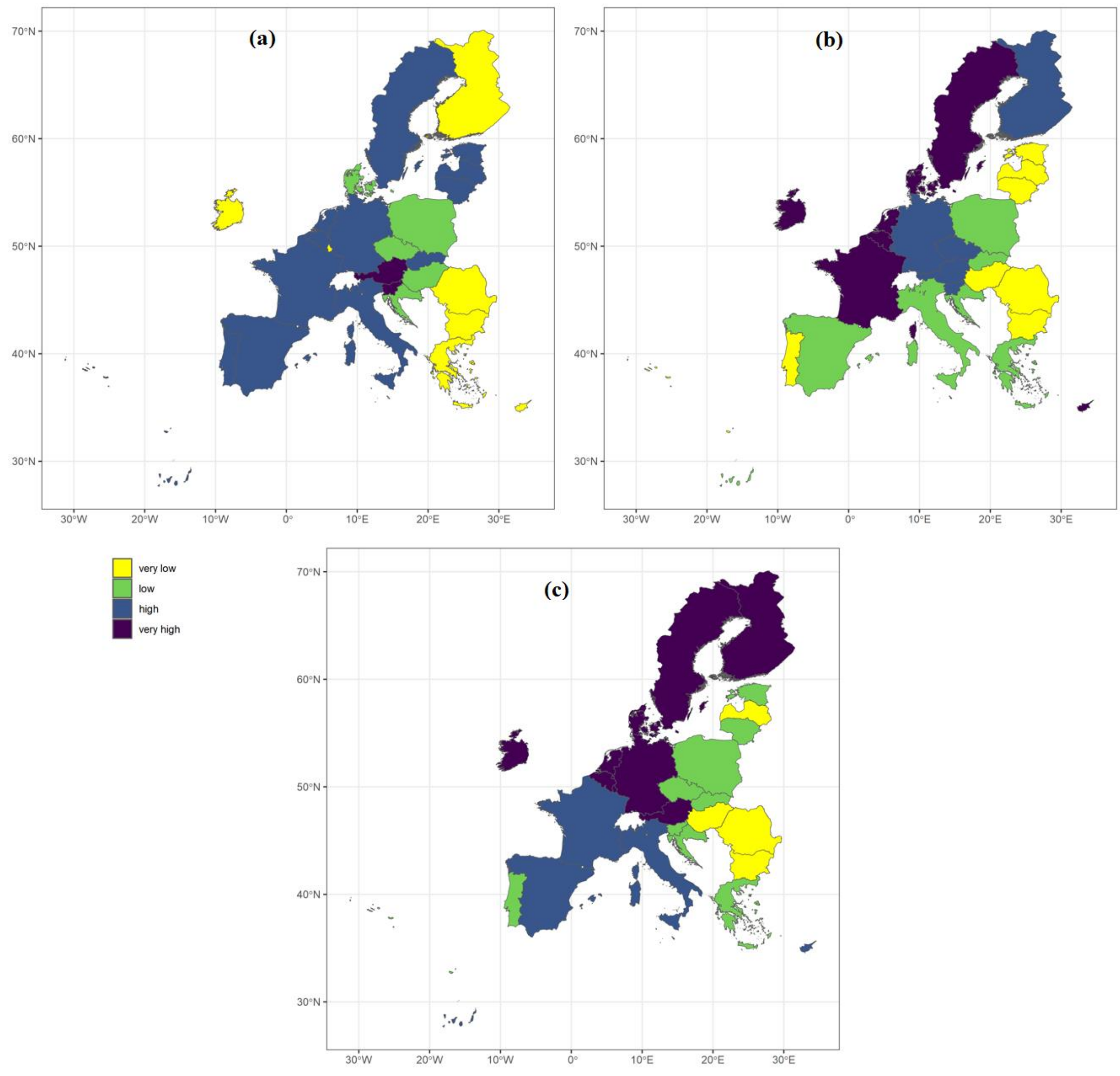
Figure 1. The spatial differentiation of the sustainable development measures in case of environmental (a), social (b) and economic (c) pillars in 2015



In turn, Figure 2 shows the spatial differentiations of measures of the three pillars of SD in 2022 in the same arrangement as in Figure 1, i.e., part (a) presents the environmental situation, part

(b) contains the map with social sustainability achievement levels, and part (c) demonstrates the spatial diffusion of GDP per capita. Comparing the environmental situation in 2022 to that from 2005, Belgium, the Netherlands, and Slovakia moved to a cluster of countries with measure values above the median. On the other hand, ecological sustainability relatively worsened (considering the relations between all countries) in Bulgaria and Hungary, which transferred to a cluster with very low and low environmental situations. The divisions on the clusters of countries with social and economic sustainability above and below the median did not change from 2015 to 2022. There were only slight transfers within them (please compare parts (b) and (c) of Figures 1 and 2).

Figure 2. The spatial differentiation of the sustainable development measures in case of environmental (a), social (b) and economic (c) pillars in 2022



Based on the spatial differentiations of sustainable development pillar measures, we can presume the occurrence of spatial autocorrelation that is stronger in the case of social and ecological dimensions than for the environmental situation. The results of Moran's I test for spatial autocorrelation are presented in Table 4.

Table 4. The results of spatial autocorrelation identification

Statistics	Environmental sustainability	Social sustainability	Economic sustainability
Moran's *I*	0.0614	0.4562	0.6001
p-value	0.1623	0.0000	0.0000

The Moran's statistics for environmental sustainability is not statistically significant because the p-value exceeds the established significance level of 0.05. Additionally, the value of the statistic is very small (0.0614), so we can conclude the absence of dependence in the case of environmental sustainability between neighbouring countries in the EU. In accordance with the p-values regarding the social and economic pillar measures, we can note that the Moran's *I* statistics is statistically significant. Based on the positive value of the *I* statistics, we can claim that the neighbouring countries present a similar level of achievement in social and economic sustainability. However, this similarity is higher in the case of economic sustainability, where the *I* statistics is equal to 0.6001 (compared to 0.4562 for the social situation). These results confirm the need to include the spatial dependence factor in the analysis of interconnections between all pillars of sustainable development.

Before the estimation of the VAR model, the stationarity of endogenous variables using the Levin-Lin-Chu test is studied. The results of the stationarity test are presented in Table 5. Based on them, we can conclude that all dependent variables characterised by individual dimensions of Sustainable Development are stationary. According to the p-values, we can reject the null hypothesis about the occurrence of a unit root in all phenomena.

Table 5. The results of the Levin-Lin-Chu stationarity test for explained variables.

Variable	z-statistics	p-value	Conclusion
Environmental sustainability	-2.9609	0.0015	Stationary
Social sustainability	-11.4939	0.0000	Stationary
Economic sustainability	-3.91738	0.0000	Stationary

Based on the above analysis, the spatial Vector Autoregression model was estimated and verified. Table 6 presents the final results of the SpVAR model estimation and verification. The interconnections between environmental, social, and economic pillars are considered in terms of changes in economic structure; that is why the variables characterising the economy's servitisation and industrialisation level and their spatial lags are added as well (estimations of parameters β_2^j, β_3^j, γ_1^j and γ_2^j, respectively).

The first equation concerns the impact of the two remaining pillars on environmental sustainability. Here, only the influence of the economic situation (in the given and neighbouring countries) turned out to be statistically significant (the p-values for the parameters α_3^j and γ_5^j are lower than 0.05). The negative estimates of the mentioned parameters indicate that the improvement in economic sustainability is not favourable for environmental development. In turn, changes in the economic structure through its servitisation positively and significantly influence the ecological situation in the EU (positive estimate of the parameter β_3^j), in contrast to changes toward the economy's industrialisation, where the negative assessment of the β_2^j denotes the destruction of the natural environment due to industrial sector development. Any changes in the economy structure in the neighbouring countries improve the ecological sustainability in the given territorial unit (see estimates of parameters γ_1^j and γ_2^j in the first equation). The estimation and statistical significance of the parameter β_1^j shows that the environmental situation in the EU improved during the considered study period. Despite the lack of spatial autocorrelation for the environmental sustainability indicator, in terms of the economy transformations the neighbourhood turned out to be relevant for ecological sustainability achievement.

Table 6. The results of estimation and verification of the SpVAR model regarding interconnections between SD pillars

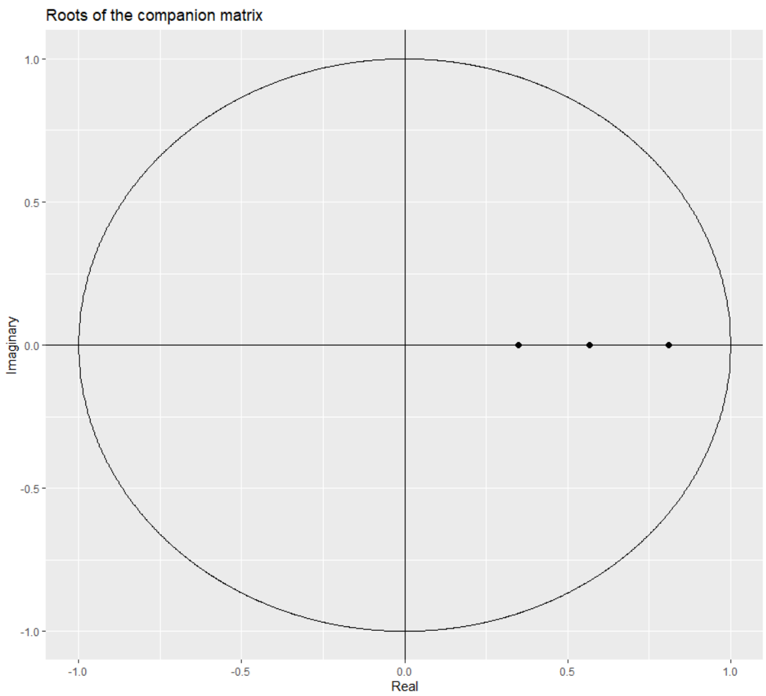
Variable	Eq1 - ENV	Eq2 – SOC	Eq3 - ECO
ENV(-1) (α_1^j)	0.5751 *** (0.1106)	0.1288 (0.1676)	-0.1365 * (0.0684)
SOC(-1) (α_2^j)	0.0220 (0.0354)	0.4055 *** (0.0724)	0.1077 * (0.0533)
ECO(-1) (α_3^j)	-0.1210 *** (0.0158)	0.0451 (0.0267)	0.7447 *** (0.0117)
Time (β_1^j)	0.0169 * (0.0077)	0.0031 (0.0127)	0.0045 (0.0051)
Industry (β_2^j)	-0.0877 * (0.0354)	-0.1240 (0.0696)	0.2904 *** (0.0412)
Services (β_3^j)	0.1152 ** (0.0442)	-0.0528 (0.0369)	0.3495 *** (0.0370)
W_Industry (γ_1^j)	0.0978 *** (0.0113)	-0.1519 *** (0.0246)	-0.0229 (0.0258)
W_Services (γ_2^j)	0.2472 *** (0.0519)	0.0515 (0.0719)	0.0504 * (0.0254)
W_ENV (γ_3^j)	0.2710 *** (0.0706)	0.2086 (0.1390)	-0.0240 (0.0529)
W_SOC (γ_4^j)	0.0097 (0.0244)	0.2697 *** (0.0587)	-0.0151 (0.0506)
W_ECO (γ_5^j)	-0.0571 * (0.0263)	0.0480 (0.0302)	-0.0106 (0.0206)
Const (β_0^j)	0.0138 * (0.0069)	-0.0226 ** (0.0081)	0.0897 *** (0.0105)

In turn, social sustainability does not depend significantly on the development in the two remaining pillars (p-values for parameters γ_1^2 and γ_3^2 are higher than 0.05). We can notice the statistical significance of the autoregression parameters regarding both time and space dimensions. The estimations of parameters α_2^j and γ_4^j in the second equation are positive. The relevance of the positive γ_4^j parameter indicates the similarity of the social sustainability level in neighbouring countries. Among the economy transformation factors, only the industrialisation process from neighbouring countries significantly influences social sustainability in a negative way, which is confirmed by the negative estimate of parameter γ_1^j in the second equation.

From the estimation of the third equation, we can conclude that environmental and social sustainability are relevantly linked with economic development. The estimation of parameter α_1^j is negative, which denotes that desirable changes in the ecological situation weaken the economic development of EU countries. On the other hand, α_2^j informs us that the improvement of social conditions has a positive influence on the economic aspect of sustainable development. Similarly, as in the case of environmental sustainability, changes in the economic structure of the given countries and their neighbours towards servitisation support economic sustainability, but the strength of the connection is much more substantial. Moreover, the industrialisation process also supports the economic growth of countries.

In all equations the parameters regarding the time lag of the dependent variable are statistically significant, and their estimations are lower than one. This proves that the estimated VAR model is stable, which is confirmed by Figure 3, where all eigenvalues of the companion matrix are inside the unit circle.

Figure 3. The eigenvalues stability conditions of VAR model



5. Conclusions

The analysis shows the significance of interconnections between three crucial pillars of sustainable development: environmental, social, and economic. The research is conducted in terms of the economic transformation of countries. Nowadays, the European Union countries are heading towards a higher use of services. This increasingly observed process is known as servitisation. In this research, the impact of the economic modifications on sustainable development is also considered.

Calculating the composite indicators for environmental and social sustainability allows for the evaluation of the differences in the level of sustainability achievement across the European Union. For economic sustainability assessment, the Gross Domestic Product was used. According to social and economic sustainability achievement, there is a visible division of units into two separate clusters. In the group with relatively higher values of indicators, countries located in the western and northern parts of the EU area are included. The countries situated in the eastern and southern parts of the EU constitute the second regime. Moreover, a high correlation between economic and social conditions is presented. Countries that are relatively more developed are characterized by better social conditions. This relationship is confirmed by the rankings compatibility test. The opposite situation refers to environmental sustainability, where there is no unequivocal division of the EU area into two separate clusters. The countries with high and low values of the ecological indicator are diffused across the whole considered territory. The differences are also confirmed by the spatial autocorrelation analysis. The significance of spatial autocorrelation statistics indicates the relevance of the connections between neighbouring units according to economic and social sustainability, not according to environmental situations. The neighbourhood is defined based on the common land border criterion. Thus, taking into account the spatial connections in the interconnection models is highly recommended.

The analysis of interconnections between sustainable development pillars based on the spatial VAR model shows that there is a two-way significant dependence between economic and environmental pillars. Economic and environmental sustainability are mutually exclusive. In the EU, based on the conducted analysis, the focus on the ecological situation harms economic development and vice versa. Moreover, there is only a one-way dependence between social and economic sustainability, where they are heading in the same direction—the improvement of social sustainability supports economic growth. There is no dependence between social and environmental sustainability concluded. Moreover, there is a similarity in the level of sustainability achievement between neighbouring countries in the case of the environmental and economic pillars in terms of economy structure modifications. The confirmation is the significant spatial autoregression parameter in the first and third equations of the system.

For environmental sustainability, we can observe the stimulating impact of economic modification towards servitisation (in the given country and also in neighbouring ones) and, in contrast, the negative impact of industrial improvement (in the given country). The economic transformation in any way supports the achievement of economic sustainability. Only in the case of social sustainability do the economic modifications observed in the given country not show a significant impact. There is also a conclusion regarding the negative influence of the progressing industrialisation process in neighbouring countries on the social conditions in the given territorial unit.

Based on this analysis, the governments have to decide what regulations should be introduced in order to provide simultaneous environmental and economic sustainability. It is easier to maintain mutual ecological and economic development in relatively wealthier countries. Therefore, the rulers should find ways to improve economic growth without harming the natural environment. They can try to find solutions in neighbouring countries. As this analysis showed, these connections are significant in the search for sustainability.

Further analysis will be based on the examination of interconnections between crucial sustainable development pillars in two separate regimes. Moreover, additional neighbourhood matrices will be employed. The significance of neighbourhoods defined according to economic similarity will be assessed.

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