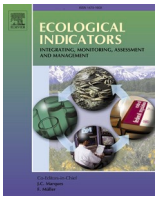
Ecological Indicators 146 (2023) 109888

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



SDGs implementation, their synergies, and trade-offs in EU countries – Sensitivity analysis-based approach

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ARTICLE INFO

Keywords:
Composite indicators
Sensitivity analysis
Sustainable development goals
Sustainable development

ABSTRACT

Sustainable development is one of the most urgent challenges facing humanity. Its basic principle is to improve people's well-being and maintain it over time. In 2015, the United Nations approved 17 sustainable development goals (SDGs) to ensure a better and sustainable future for all, balancing economic, social and environmental development. SDGs create an 'indivisible whole'; thus, examining their interactions is crucial. Our goals were twofold: (i) to assess the implementation degree of SDGs in EU countries and (ii) to examine the interactions between goals. The potential to achieve a given SDG is approximated by a composite indicator, calculated based on an innovative method of implementing tools derived from sensitivity analysis (SA). Respecting the degree of variability of individual variables and their correlation, we set the weights to equalise their importance. Moreover, the application of SA allows us to remove strongly correlated variables that are not transferring supplementary information. We use countries' linear ordering and Spearman's rank correlation coefficient to assess interactions between SDGs.

Our research shows that Scandinavian countries predominately occupy the leading positions, respectively, eight times on the podium for Sweden and four by Denmark (of which three as a leader). The Netherlands also stands out, occupying the superior position in the performance of SDGs 2, 3, 5, 8, 9, 12 and 17. The top in achieving one of the most priority area – no poverty (SDG1) belongs to Czechia. Our study confirmed the results obtained by many researchers regarding the more potent synergy between SDGs compared to the trade-offs. The only trade-offs observed in our study relate to SDG15, which negatively correlated with SDG3 and 17. Furthermore, SDG7 was the only one not associated with others.

1. Introduction

On September 15, 2015, the United Nations (UN) adopted a comprehensive development plan, "2030 Agenda for Sustainable Development". Thus, all 193 UN Member States have committed themselves to take action to achieve 17 Sustainable Development Goals (United Nations, 2022).[2] The Agenda focuses on five overlapping aspects that are vital to humanity and the planet (the so-called 5xP): People (SDGs 1–5), Planet (SDGs 6–7 and 13–15), Prosperity (SDGs 8–12), Peace (SDG16) and Partnership (SDG17) (Agenda, 2015). The Agenda's recommendations should be translated into an effective policy embedded in each country's specific resources and conditions (Bellantuono et al., 2022). The diversity of patterns' implementation in a given country determines the array of similarities and differences between goals. Problems emerging in sustainable development research are often tough to overcome, as SDGs cover various issues which are arduous to define and quantify (Łuczak and Just, 2021).

Despite the cognisance that the SDGs are essential to humankind, their implementation in different countries is progressing at diverse rates (Yang et al., 2020). Sachs et al. (2021) emphasised that poverty eradication (SDG1) and equality enhancement (SDG5) are top priorities, denoting that some SDGs are more paramount than others.

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[1] Financed within the framework of the program of the Minister of Science and Higher Education under the name "Regional Excellence Initiative" in the years 2019–2022; project number 001/RID/2018/19; the amount of financing PLN 10,684,000.

[2] The list of sustainable development goals and their short description is presented in the Appendix in Table A.1.

https://doi.org/10.1016/j.ecolind.2023.109888
Received 5 September 2022; Received in revised form 23 November 2022; Accepted 7 January 2023
Available online 16 January 2023

Table 1
Review of studies on the interaction between the goals of SDGs.

Research	Dataset	Investigated SDGs	Method	Results
Pradhan et al. (2017)	227 countries between 1983 and 2016	All SDG	Nonparametric Spearman's rank correlation	Positive correlations outweigh negative ones. SDG1 link to progress toward SDGs 3, 4, 5, 6 and 10. SDG3 is in line with progress in SDGs 1, 4, 5, 6 and 10.
Singh et al. (2018)	Marine and oceanic areas	Focus on SDG14	Rapid assessment methodology - operationalizes a framework for identifying the dependencies (co-benefits) and hindrances (trade-offs) among directional relationships	SDGs 1, 2, 11, 13, 15 and 16 positively relate to every ocean target (SDG14). SDG1 is related to six of the seven ocean targets, and SDG2 interacts with five of them. Only SDGs 3, 5, 6 and 7 are positively associated with three or fewer of the ocean targets.
Kroll et al. (2019)	193 UN member states in 2010–2018,	All SDG	Spearman's rank correlation coefficient, interactions trends and projections	Synergies for SDGs 1, 3, 7, 8 and 9; and trade-offs for SDGs 11, 13, 14, 16 and 17.
Miola and Schiltz (2019)	EU28	All SDG	Three ways to measure SDGs: (i) the average for all indicators at the goal level, (ii) the Organisation for Economic Cooperation and Development (OECD) distance measure and (iii) the measure of SDG performance based on the monitoring report by Eurostat on the progress towards the SDGs in an EU context.	The relative position of a country depends almost exclusively on the chosen method and indicators set.
Fonseca et al. (2020)	193 UN member states,	All SDG	Spearman's rank correlation coefficient	Domination of positive interactions. SDGs 2, 3, 4, 7, 8, and 11 indicate strong positive correlations with others. SDG 12 exhibits moderate or strong negative correlations.
Yang et al. (2020)	Worldwide survey in 2018 and 2019	All SDG	Linking SGDs with ES (ecosystem services – such as climate regulation, fresh water, food, water purification, biodiversity and education).	The synergies' excess over trade-offs.SDG 1 correlated with SDGs 2, 3, 5 and 8; SDG 14 correlated with SDG 15; SDG 5 correlated with SDG 10.ES connected with SDGs 15, 13, 14 and 6.
Halkos and Gkampoura (2021)	UN's data	All SDG	Literature review, an assessment of the relevance and contribution of each SDG to sustainable development and an indication of the extent to which the evolution of key indicators reflects progress towards these objectives	Progress in executing SDGs 8, 9, 12 or 14, while SDGs 2, 6, 11, 13 and 16 lag.
Sompolska-Rzechuła and Kurdyś-Kujawska (2021)	European countries in 2010 and 2018	SDG3 and 13	TOPSIS method	Implementation of SDGs 3 and 13 in most European countries was a compromise.
Warchold et al. (2021)	247 countries and worldwide areas between in 1990–2019	All SDG	Cross-sectional correlation analysis	Synergies always prevail over trade-offs, and linear interactions outweigh non-linear ones. SDGs' interactions vary depending on the country's income, demographic profile and population distribution.
Bellantuono et al. (2022)	Selected countries,	All SDG	Multiplex consisting of three layers, each containing 17 nodes representative of the goals	The strongest links include SDG 9, 17, 12, 13, 8 and 14. Weak link is shown by SDG 5, 7 and 6.
Elavarasan et al. (2022)	40 European countries in 2018	SDG7	Composite indicator, weights assigned based on Analytic Hierarchy Process (AHP). Sensitivity analysis was used to identify the most influential indicators.	The most influential factors were clean energy conversion and energy security.
Zhang et al., (2022)	China, different statistical departments since 1990	All SDG	Composite indicator (CI) with equally weighted variables. SDGs division into three categories: essential needs, objectives and governance.	SDGs in "essential needs" and "objectives", as well as "essential needs" and "governance", show compromises in the eastern provinces and also in some central and western provinces of China.

Source: Authors' investigation.

Understanding the complex relationships between SDGs' implementation is critical in supporting policy-makers in creating and applying social, economic, and environmental policies (Scharlemann et al., 2020).

This research revises the interactions between the SDGs in EU countries. A multivariate statistical analysis, including the linear ordering of objects, is the primary tool that allows us to analyse this complex phenomenon effectively. Two main research goals were set in our study:

(i) Potential assessment of European Union countries to implement SDGs (proprietary composite indicator based on sensitivity analysis);

(ii) Synergy and trade-off indications among SDGs (linear ordering and Spearman's rank correlation coefficient). A statistically significant positive correlation among SDGs indicates the occurrence of synergy, while a negative one reveals a trade-off.

To achieve our research goals, we refer to sixteen SDGs (SDG14 was excluded due to lack of data) and study their interactions based on the Eurostat database from 2020. The novelty of our study is grounded on the use of sensitivity analysis (SA) tools to establish weights to obtain the desired importance of all variables. SA allows us to consider the variables' differentiation and correlation during the weighing process.

The structure of our article is as follows: an introduction outlines the main goals of the investigation and explains our motivations. The second section provides a literature review, starting with a brief description of SDGs, evidencing approaches in SDGs analysis, and surveying interactions among SDGs. The third section is devoted to the research methods and data used. The fourth section comprehensively describes the research results. The article ends with an extensive discussion and conclusions.

2. Literature review

The Report (European Commission, 2022) emphasises that sustainable development is firmly rooted in European treaties and has long been at the heart of European politics. SDGs builds on the Millennium Development Goals (MDGs) and the relationship between them has been

examined by de Jong and Vijge (2021). The authors concluded that the SDGs represent a much more integrated approach to sustainable development than the MDGs, focusing on the interplay between prosperity, planet, partnership and peace. The SDGs are thus 'indivisible and interconnected' with a strong emphasis on 'political and institutional coherence'. Sustainable development economic and ecological components are nowadays at the SDG's core. The focus has shifted from poverty reduction in the MDGs toward integral development (including poverty reduction).

The 2030 Agenda have given new impetus to global efforts to achieve sustainable development. Thus exploring synergies and emerging trade-offs that arise from the relationship between goals is crucial to achieving long-term sustainability results. The aforementioned report emphasises that more positive than negative (24.1 % vs 13.4 %) interrelationships between goals occur, but no significant correlation was found in 62.4 % of indicators' pairs. Understanding the nature of the interrelationship between the SDGs is key to unlocking their full potential and ensuring that progress in one area is not delivered at the expense of another.

Table 1 provides an overview of the research results focusing on the relationship among SDGs. Table 1 is also a review of the methodological approaches used in the SDGs measurement.

The literature review (Table 1) shows that some studies explore synergies and trade-offs between all SDGs, while others focus on the chosen SDG or some of 169 specific targets. In most cases, SDG1 and SDG3 are closely related to others, while SDG 2 is a trade-off target. The observed synergies show the broad compatibility of sustainable development goals, in which progress towards one goal can use the achievement of other goals (Pradhan et al., 2017). Researchers use various methods to assess the degree of SDG implementation and determine their interactions, from correlation, time series, and multivariate data analysis methods to multi-criteria decision-making (MCMD) methods and neural networks.

3. Methods and data

To achieve our research goals, we refer to sixteen SDGs (SDG14 was excluded due to lack of data) and study their interactions based on the Eurostat database from 2020. Data availability was 99.1 %; in the case of statistical information absence, the naïve approach was used (Hyndman and Athanasopoulos, 2018), i.e. the most recent non-missing value (almost entirely from 2019). In this research paper, proprietary composite indicators (CIs) were constructed for the linear ordering of the European Union countries according to their SDGs implementation degree. Our approach differs from most scientific studies as we use methods based on sensitivity analysis to determine the appropriate weights and to reduce the variables set. The weights were established so that each variable included in a given SDG has equal importance, i.e. equally explains the ranking of countries in terms of the SDG under investigation.

There exists a rich critical literature related to the construction of composite indicators (Ravallion, 2010; Paruolo et al., 2013; Becker et al., 2017; Gnaldi & Del Sarto, 2018; Muller, 2018; Greco et al., 2019; Cartone & Postiglione, 2020; Cinelli et al., 2020; Kuc-Czarnecka et al., 2020). However, it should be noted that there are also works in which various methods of repairing composite indicators are used: multi-attribute utility (Cracolici & Nijkamp, 2008), data development analysis (Zhou et al., 2010; Martí et al. 2017), factor analysis (Zizka, 2013), principal component analysis (Perisic, 2015), multidimensional IRT fuzzy synthetic evaluation (Haider, et al., 2018). The OECD handbook OECD (2008) for constructing CIs has existed for over a decade. Nevertheless, not all CIs follow recommendations. For example, analyses of the uncertainty and sensitivity (Saisana et al., 2005; Dobrota et al., 2015; Becker et al., 2017; Kuc-Czarnecka et al., 2021; Olczyk et al., 2022) are rare, which is an obstacle to their transparency. One of the major drawbacks of linear aggregation – although very intuitive – is the confusion between weights and importance. It should be emphasised that weight is not the same as importance (Paruolo et al., 2013). In many cases, weights assigned by CIs creators do not reflect individual factors' actual degree of influence. They may rather reflect the developers' understanding of the importance, which is erroneous and far removed from the definition of importance that makes mathematical sense (rooted in ANOVA). While this should convince all developers to use better strategies for rating and ranking, e.g. based on multi-criteria analysis or sensitivity analysis, we observe in practice (from university ranking and countries' performance to indicators of the rule of law and freedom of the press (Bandura, 2008; 2011; Yang, 2014) a predominance of linear aggregation strategies for a reason linked to the apparent simplicity and transparency of the method.

We assumed that since the variables are listed in the database and no other Eurostat studies have specified otherwise, each target is equally important to achieve examined SDG. So, we create a measure that reflects the equal importance of these variables while removing diagnostic variables that have low information transfer, i.e. having an impact on the final CI only because they correlate strongly with the remaining variables (Lindén et al., 2021b). A literature review (Bandura, 2008; 2011; Yang, 2014) found that developers most often eschew better strategies for ranking derived from decision science and use instead linear aggregation to measure complex phenomena. To illustrate how this popular aggregation method can be improved, the procedure for creating our composite indicators was as follows:

1. Construction of composite indicator as the weighted arithmetic mean (separately for each SDG):

$$y_j = \sum_{i=1}^{d} w_i x_{ji}, \qquad j = 1, 2, \cdots, d; i = 1, 2, \cdots, n, \tag{1}$$

where:y_j– the value of the composite indicator for the j-th country,x_{ji}– the normalised value of the i-th variable in the j-th country,w_i– weight assigned to the i-th variable.

2. Determination and isolation of the impact of x_i on y using the first-order sensitivity index (Saltelli et al., 2000):

$$S_i \equiv \frac{V_{x_i}(E_{x\ i}(y|x_i))}{V(y)} \tag{2}$$

where:S_i– first-order sensitivity measure, $S_i \in [0, 1]$,$x_{\ i}$– vector containing all variables but x_i,$E_{x\ i}(y|x_i)$– expected value of y at a given value of x_i with the expectation taken over $x_{\ i}$,$V(y)$– unconditional variance of y.

3. Decomposition of the first-order sensitivity index:

$$S_i = S_i^u + S_i^c \tag{3}$$

where:S_i^u– uncorrelated contribution, understood as unique variability that can only be explained by variable x_i,S_i^c– correlated contribution, the variability caused by all variables associated with variable x_i.

This decomposition allows to determine whether the variable's influence results from its correlation with other variables ($S_i^c \approx S_i$) or whether x_i carries a sufficiently high information load in itself.

4. Estimation of uncorrelated contribution by finding the residuals using penalised splines (Harezlak et al., 2018):

$$\widehat{z}_i = x_i - \widehat{x}_i = x_i - \left(\beta_0 + \sum_{l \neq i}^{d} \widehat{\beta}_l x_i\right) \tag{4}$$

where:$\widehat{z}_i$– residuals of a regression of x_i on $x_{\ i}$,β_0– y-intercept from multivariate linear regression,β_l– coefficient from multivariate linear regression.

Penalised splines are an extension of linear parametric regression, but they also have the capabilities of nonparametric regression.

$$S_i^u = \frac{\sum_{j=1}^{n}\left(\widehat{y}_j^{(\ i)} - \overline{y}^{(\ i)}\right)^2}{\sum_{j=1}^{n}\left(y_j - \overline{y}\right)^2} \tag{5}$$

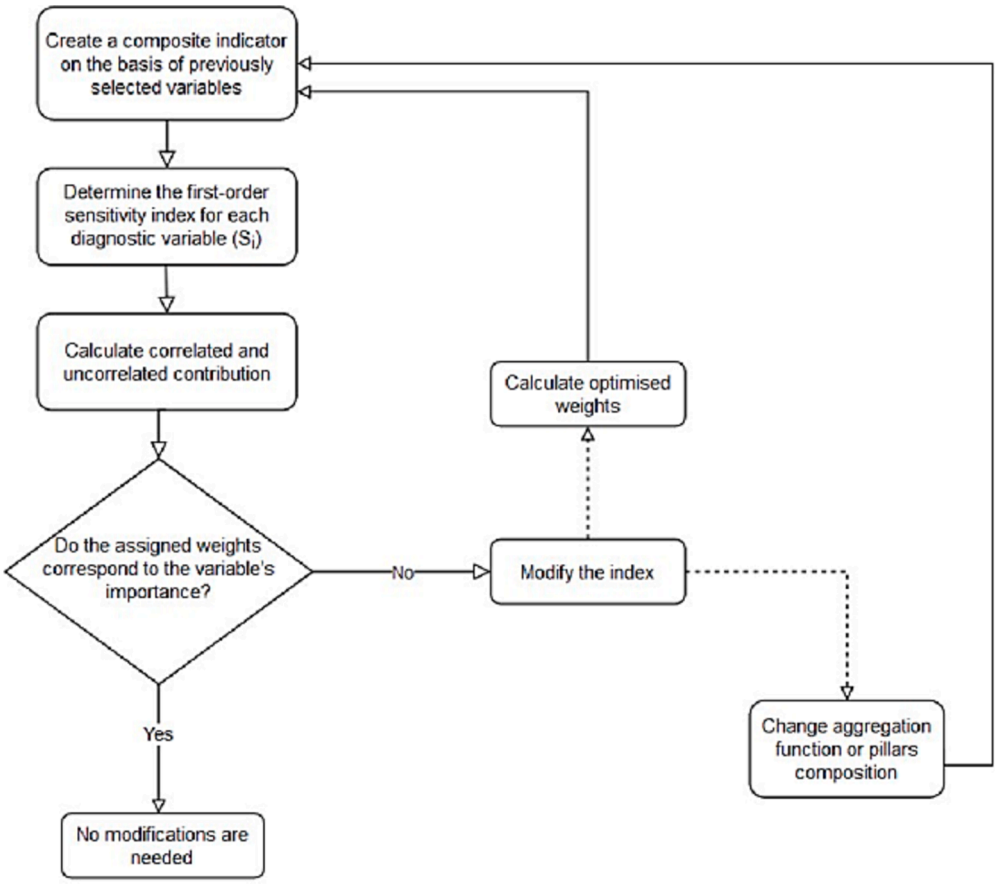

Fig. 1. Composite indicator's compliance testing procedure.
Source: Kuc-Czarnecka, et al., (2021)

where:$\widehat{y}_j^{(i)}$– non-linear regression fitted values,$\overline{y}^{(i)}$– average value of $\widehat{y}_j^{(i)}$,y_j– composite indicator value in the j-th object,$\overline{y}$– average value of y_j.

5. Estimation of correlated contribution:

$$S_i^c = S_i - S_i^u \tag{6}$$

4. Weight optimisation (Becker et al., 2017) using the Nelder–Mead method (Nelder & Mead, 1965):

$$w_{opt} = argmin_w \sum_{i=1}^{d} \left(\widetilde{S}_i^* - \widetilde{S}_i(w) \right)^2 \tag{7}$$

where:$\widetilde{S}_i^*$– target normalised correlation ratio,w– set of initial weights assigned by CI creator, $w = \{w_i\}_{i=1}^d$,

$\widetilde{S}_i$– normalised correlation ratio of x_i, computed as:

$$\widetilde{S}_i = \frac{S_i}{\sum_{i=1}^{n} S_i} \tag{8}$$

The optimisation algorithm relocates the weight to match the target correlation ratios, i.e., each variable's intended relative importance. The CIAO (Composite Indicator Analysis and Optimisation Tool) Matlab package was used for numerical analyses (Lindén et al., 2021a).

5. Construction of final composite indicator as the weighted arithmetic mean (1) using optimal weights (7).

6. Linear ordering of EU countries.

A graphic presentation of the above procedure is described in Fig. 1.

The proposed methodological approach was used to evaluate the implementation of SDG in the EU countries using data from the Eurostat database. The set of 111[3] variables that met the data availability conditions was reduced using the above procedure. Table A2 in the Appendix presents the final list of diagnostic variables broken down by individual goals. It also includes basic descriptive statistics for the indicated variables and their impact direction (stimulant - the higher the value, the better; destimulant - the lower the value, the better). It can be noticed that some variables have very high variability (coefficient of variation above 100 %), which proves significant differences between EU countries. The variables with the highest coefficient of variation are e.g. SDG_03_60, SDG_06_10, SDG_09_70, SDG_10_60, SDG_13_50 and SDG_15_50. When analysing the asymmetry of individual variables, we found that they differ substantially, from very weak (e.g. for SDG_03_11, SDG_04_20 or SDG_08_60) to extreme asymmetry (e.g. for SDG_01_50, SDG_06_10 or SDG_12_50). A right-handed asymmetry characterises the vast majority of variables. Table A3 in the Appendix contains the optimal weights for individual variables used to calculate CIs according to formulas (1)-(8).

4. Results

As a result of the procedure described in the previous section, 16 composite indicators were obtained, showing the degree of implementation of SDGs in the EU countries. For each SDG (except 14), EU

[3] Due to the lack of data, the variables concerning SDG14 were omitted. It should also be noted that some variables appear in several SDGs, therefore they were counted once.

Table 2
Values of CIs for each SDG.

	SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG15	SDG16	SDG17
Austria	0,1598	0,1033	0,1089	0,1190	0,1554	0,4885	0,1196	0,1202	0,1272	0,0602	0,0945	0,1490	0,0900	0,1556	0,1918	0,0945
Belgium	0,1206	0,1501	0,1251	0,1467	0,1751	0,4740	0,0831	0,1437	0,1337	0,0412	0,0863	0,1593	0,1212	0,1516	0,1651	0,1395
Bulgaria	0,1055	0,1152	0,0822	0,0506	0,1064	0,4104	0,0721	0,0862	0,1070	0,0302	0,0626	0,0882	0,0770	0,2029	0,0878	0,0574
Croatia	0,1463	0,1108	0,0687	0,1178	0,1355	0,4911	0,1208	0,0932	0,0960	0,0370	0,0883	0,1336	0,1028	0,2002	0,1741	0,0697
Cyprus	0,1718	0,1000	0,1130	0,1028	0,0787	0,2500	0,0798	0,0831	0,0834	0,1084	0,0670	0,1291	0,0809	0,1082	0,1192	0,0788
Czechia	0,1879	0,1356	0,0953	0,1056	0,1020	0,4312	0,0958	0,1283	0,0964	0,0698	0,0966	0,1479	0,0413	0,1721	0,1522	0,0687
Denmark	0,1349	0,2055	0,1210	0,1410	0,1731	0,4907	0,1433	0,1433	0,1267	0,0602	0,0843	0,1523	0,1342	0,1409	0,2090	0,1086
Estonia	0,1318	0,0819	0,0505	0,1238	0,1145	0,4311	0,1117	0,1178	0,1051	0,0499	0,1022	0,0554	0,0744	0,1753	0,1511	0,0707
Finland	0,1360	0,1109	0,0980	0,1288	0,1768	0,4962	0,0906	0,1556	0,1264	0,0624	0,0994	0,1196	0,1139	0,1827	0,1803	0,0943
France	0,1282	0,1714	0,0946	0,1547	0,1835	0,4745	0,1059	0,1001	0,1121	0,0485	0,0697	0,1881	0,1506	0,1587	0,1267	0,1180
Germany	0,1451	0,1579	0,1253	0,1151	0,1211	0,4817	0,1020	0,1353	0,1171	0,0644	0,0819	0,1536	0,1323	0,1933	0,1925	0,1081
Greece	0,0720	0,1403	0,0836	0,0847	0,1482	0,3618	0,0985	0,0697	0,0707	0,0362	0,0610	0,1319	0,0997	0,1659	0,0972	0,0892
Hungary	0,1466	0,1213	0,0953	0,0978	0,0815	0,4786	0,1017	0,1229	0,1019	0,0496	0,0836	0,1400	0,0932	0,1510	0,1615	0,0925
Ireland	0,1241	0,1846	0,1215	0,1760	0,1792	0,4891	0,1392	0,1543	0,1121	0,0705	0,0951	0,1419	0,0795	0,1387	0,2004	0,1097
Italy	0,0986	0,1546	0,1218	0,0971	0,1099	0,4403	0,1123	0,0911	0,0758	0,0167	0,0770	0,1812	0,1211	0,1155	0,1528	0,1053
Latvia	0,0978	0,0778	0,0569	0,1364	0,1212	0,4159	0,1234	0,0938	0,0981	0,0443	0,0691	0,1309	0,1128	0,1701	0,0807	0,0754
Lithuania	0,1353	0,1110	0,0743	0,1394	0,1527	0,4225	0,0825	0,0882	0,1651	0,0514	0,0748	0,1225	0,1007	0,1627	0,1352	0,0882
Luxembourg	0,1420	0,1528	0,1125	0,1238	0,1723	0,4906	0,0608	0,0840	0,1281	0,0887	0,0831	0,1524	0,0435	0,1887	0,1804	0,1179
Malta	0,1740	0,0698	0,1197	0,0881	0,0644	0,4359	0,0982	0,1187	0,0909	0,0793	0,0696	0,1395	0,0703	0,1400	0,1389	0,1099
Netherlands	0,1505	0,1723	0,1451	0,1386	0,1999	0,4863	0,0980	0,1603	0,1588	0,0708	0,0702	0,2038	0,1048	0,1534	0,1633	0,1408
Poland	0,1410	0,1152	0,1034	0,1354	0,0982	0,4611	0,1061	0,1001	0,0939	0,0558	0,0796	0,1289	0,0433	0,1606	0,1751	0,0836
Portugal	0,1537	0,1217	0,0957	0,1230	0,1467	0,4516	0,1087	0,1075	0,0630	0,0481	0,0589	0,1265	0,1143	0,1670	0,1671	0,1395
Romania	0,0859	0,1404	0,0739	0,0245	0,0776	0,2305	0,1189	0,0949	0,1036	0,0339	0,0583	0,1178	0,0818	0,1447	0,1298	0,0853
Slovakia	0,1723	0,1141	0,0924	0,0813	0,1223	0,4910	0,0980	0,1095	0,1059	0,0582	0,1025	0,1260	0,0604	0,1809	0,1683	0,0761
Slovenia	0,1775	0,1193	0,0992	0,1521	0,1672	0,4971	0,1107	0,1222	0,1259	0,0644	0,0788	0,1497	0,0846	0,1823	0,1700	0,1042
Spain	0,1116	0,1452	0,1184	0,0946	0,1158	0,4154	0,1073	0,0992	0,1014	0,0330	0,0685	0,1497	0,1231	0,1454	0,1322	0,1549
Sweden	0,1420	0,1561	0,1483	0,1483	0,1959	0,4984	0,1272	0,1550	0,1452	0,0817	0,0909	0,1343	0,1657	0,1576	0,1637	0,1082

Source: Authors' investigation.

Table 3
Ranking of European Union countries for each SDG.

Country	SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG15	SDG16	SDG17
Austria	6	23	12	15	10	9	6	11	6	11	6	10	16	17	4	14
Belgium	21	9	4	5	6	14	23	5	4	21	9	4	6	19	12	3
Bulgaria	23	17	22	26	21	24	26	24	13	26	24	26	21	1	26	27
Croatia	10	22	25	16	14	4	5	21	21	22	8	16	12	2	8	25
Cyprus	5	24	10	19	25	26	25	26	24	1	23	19	19	27	24	21
Czechia	1	13	18	18	22	19	21	8	20	7	4	11	27	9	17	26
Denmark	17	1	7	6	7	6	1	6	7	12	10	7	3	23	1	9
Estonia	18	25	27	12	19	20	9	13	15	16	2	27	22	8	18	24
Finland	15	21	15	11	5	3	22	2	8	10	3	24	9	5	6	15
France	19	4	19	2	3	13	14	17	12	18	19	2	2	15	23	5
Germany	11	5	3	17	17	11	15	7	10	8	13	5	4	3	3	11
Greece	27	12	21	24	12	25	17	27	26	23	25	17	14	12	25	17
Hungary	9	15	17	20	24	12	16	9	17	17	11	13	15	20	15	16
Ireland	20	2	6	1	4	8	2	4	11	6	5	12	20	25	2	8
Italy	24	7	5	21	20	17	8	22	25	27	16	3	7	26	16	12
Latvia	25	26	26	9	16	22	4	20	19	20	21	18	10	10	27	23
Lithuania	16	20	23	7	11	21	24	23	1	15	17	23	13	13	20	18
Luxembourg	12	8	11	13	8	7	27	25	5	2	12	6	25	4	5	6
Malta	3	27	8	23	27	18	18	12	23	4	20	14	23	24	19	7
Netherlands	8	3	2	8	1	10	19	1	2	5	18	1	11	18	14	2
Poland	14	18	13	10	23	15	13	16	22	14	14	20	26	14	7	20
Portugal	7	14	16	14	13	16	11	15	27	19	26	21	8	11	11	4
Romania	26	11	24	27	26	27	7	19	16	24	27	25	18	22	22	19
Slovakia	4	19	20	25	15	5	20	14	14	13	1	22	24	7	10	22
Slovenia	2	16	14	3	9	2	10	10	9	9	15	9	17	6	9	13
Spain	22	10	9	22	18	23	12	18	18	25	22	8	5	21	21	1
Sweden	13	6	1	4	2	1	3	3	3	3	7	15	1	16	13	10

Source: Authors' investigation.

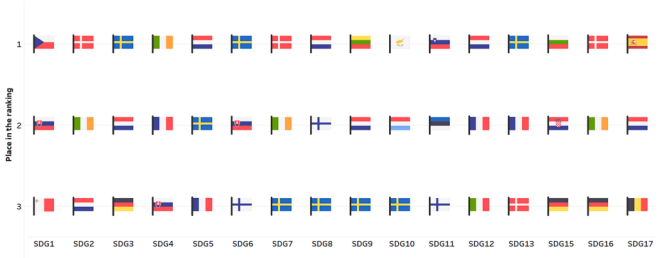

Fig. 2. Countries on the podium due to their potential to meet the SDGs. Source: Authors' investigation.

countries have been ranked to show their potential to achieve the investigated goal. The country with the highest CI value in a given SDG was rated 1, and the one with the lowest value got 27th position. Three countries have reached the first position three times: Denmark (SDGs: 2, 7, 16), Netherlands (SDGs: 5, 8, 12) and Sweden (SDGs: 3, 6, 13). The CIs and country rankings' values are presented in Tables 2 and 3, respectively. Moreover, Fig. A.1 in the Appendix shows a box-whisker plot for the CI values for each SDG.

When analysing Fig. 2, Sweden's outstanding results can be noticed (3 times first, 1 in second and 4 times in third place). Equally great potential was observed in the Netherlands (3 times in first place, 3 times in second and once in third). Another country with high scores is Denmark (three times leader and third place for SDG13). Ireland is also sound, being ranked as a leader in achieving SDG 4 and taking second place three times. France was placed second three times (SDG4, 12 and 13) and third once (SDG5). Slovenia was the second best for SDG1, 6 and third for SDG4. Finland got the silver medal for SDG8 and the bronze for SDG6 and 11.

Countries that took the leading position just once are Bulgaria (SDG15), Czechia (SDG1), Spain (SDG17), Cyprus (SDG10), Lithuania (SDG9), and Slovakia (SDG11).

We also compare how often each EU country reached CIs' values above the EU median (Fig. 3). The higher the colour saturation, the more often a given country was above the median. The leaders turned out to be Denmark and Sweden (14 times), Germany, Ireland and Luxembourg (13 times), the Netherlands and Slovenia (12 times), Belgium and Austria (11 times), and Finland, whose CI value of ten SDGs was above the median. Countries that achieved 8 to 14 goals are those with high economic indicators: actual individual consumption per capita in purchasing power standards (AIC in PPS, in 2020) and gross domestic product per capita (GDP in PPS, in 2020). Indicators for these countries exceeded the EU average (Eurostat, 2021). The exception is Ireland (only GDP) and Slovenia. Thus, high economic activity (GPD) and material welfare of households (AIC) are conducive to sustainable development. On the other hand, the worst results were achieved by Bulgaria and Romania, which had CI values above the median for only two SDGs, Greece and Cyprus (3 times) and Latvia and Poland (4 times).

The second stage of our investigation is the assessment of interactions: synergy and trade-off. Based on the ranking places of the EU countries, we determined Spearman's rank correlation coefficient for each pair of SDGs. We took into consideration only statistically significant values ($\alpha = 0.05$). Positive values indicated synergy and negative compromise. Among all couples of indicators (120[4]), only 41 (34.2 %) indicated significant interactions. Among them, 39 are positive associations, and only two are negative. Fifth SDG - gender equality (Fig. 4) has the highest number of connections (all positive). In our study, SDG5 is correlated with the following goals (according to the relationship strength): 4, 9, 6, 17, 2, 13, 8, 16, and 12. SDG5 has positive relationships with goals from all areas of sustainable development (People - SDG2, SDG4; Planet - SDG6, SDG13; Prosperity - SDG8, SDG9, SDG12, Peace - SDG16, and Partnership - SDG17). It can be concluded that SDG5 is a crucial goal with numerous positive links with others. Consequently, more advanced implementation of the objectives mentioned above also strengthens the achieved SDG5.

Goals positively correlated with many others are also SDG6 and SDG8. First of them - clean water and sanitation - achieved significant synergy with SDGs: 1, 4, 5, 8, 9, 10, 11, 16, and the second - decent work and economic growth - with SDGs: 3, 4, 5, 6, 9, 10, 11, 16. These two seemingly distant goals are related mainly to the same goals. Our research confirmed that achieving higher indicators of access to clean water (SDG6) and decent work and economic growth (SDG8) is associated with the achievement of higher indicators in the following areas: quality education (SDG4), gender equality (SDG5), industry innovation (SDG9), reducing social inequalities (SDG10), safe and sustainable cities (SDG11), peace, justice and strong institutions (SDG16). Sustainable and balanced development is possible due to the direct influence of indicators in a given area and, simultaneously, an indirect impact on other socio-economic areas. SDG3 show strong socio-economic ties with SDG2 - zero hunger (both goals from the People area), SDG8, 10, 12 (Prosperity), SDG16 (Peace) and SDG17 (Partnerships). The positive correlations of SDG16 also evidence the interpenetration of development areas with SDG3 and 5 (People), SDG6 (Planet), SDG8, 9, 10 and 11 (Prosperity).

The positive linkages between goals not mentioned so far are SDG1 & SDG10 (no poverty - reduced inequalities). Reducing poverty is as important as lowering disparities (mainly within countries). We can also specify a group of connections between the four goals: SDG2, 7, 12 and 13. Responsible consumption and production are associated with promoting the efficient use of resources, limiting climate change and its adverse effects, improving the quality of life, and reducing hunger. Thus, implementing the indicator responsible for consumption and production may affect the performance of indicators related to hunger and climate. The positive relationship of SDG17 with other goals (2, 12, 13) confirms the necessity of partnership between the government, private enterprises, and civil society. The increased cooperation results in hastened hunger reduction, adequate consumption and planet protection.

Our research also revealed synergy between SDG4 & SDG9 and SDG9 & SDG11. These links show that high-quality education is crucial for improving people's lives and sustainable development. Ubiquitous access to appropriate education enables finding innovative solutions to the most acute problems of the contemporary world. Therefore, education's quality assurance at various levels (from pre-school to higher education) and in multiple fields (including technical) empowers an educated society (sustainable lifestyle, care for human rights, gender equality, peace culture and non-violence). As was mentioned, SDG9 is related to SDG11. So, developing a reliable, good-quality infrastructure supports economic development and well-being. Quality of infrastructure, the introduction of sustainable industrial development, clean and environmentally friendly technologies, research promotion and technological improvement of the industrial sector may be activities assigned to SDG9. Their implementation enhances the safety and stability of cities and human settlements – the population's living conditions improve, and culture and science develop.

Particular attention should be paid to the study's results showing trade-offs in the relationship between the goals. We obtained two significant negative relationships: SDG15 & SDG3 and SDG15 & SDG17. For SDG15 (life on land), these are the only negative relationships with other goals. The tasks for humanity under this goal are protecting, restoring and promoting sustainable use of terrestrial ecosystems, managing forests sustainably, combating desertification, and halting and reversing land degradation and biodiversity loss.

The only goal that has no significant relationship to other goals is SDG7 (affordable and clean energy). The goal defined as 'ensure access to affordable, reliable, sustainable and modern energy for all' is a

[4] The number of calculated Spearman's rank correlation coefficients for countries' positions in the ranking according to the CI's value for given SDG.

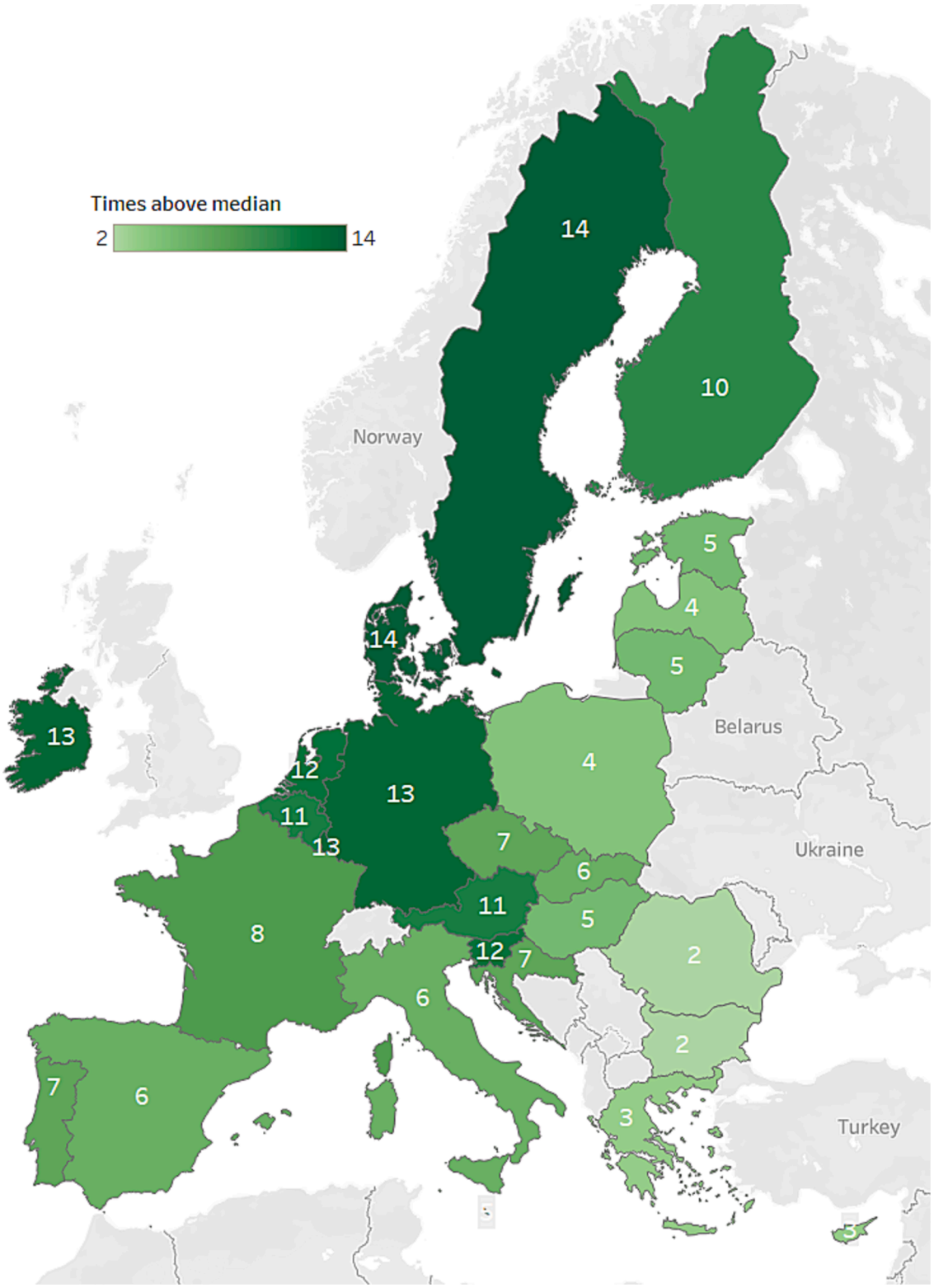

Fig. 3. Number of SDGs for which a given country achieved CI values above the EU median. Source: Authors' investigation.

specific goal that requires appropriate investment outlays. The research covers 2020, but the problem itself is still valid. In light of the issues related to the COVID-19 pandemic and the war in Ukraine, clean and cheap energy is widely discussed.

5. Discussion

Since the announcement of the SDGs in 2015, countries have started to develop strategies for effectively implementing the 2030 Agenda. We are now eight years ahead of the Agenda deadline; therefore, there is a growing need for more efficient targeting of multiple SDGs. Scientists and policymakers constantly discuss the measurement and monitoring

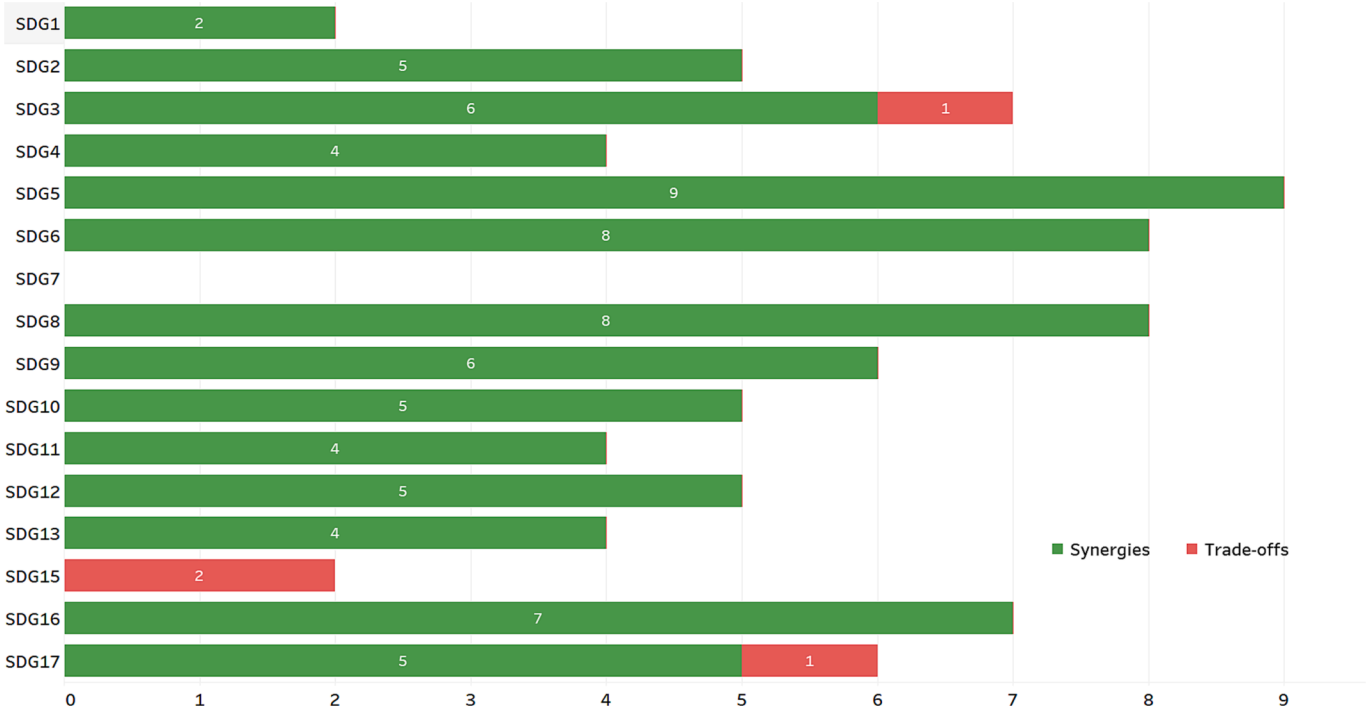

Fig. 4. Synergies and trade-offs for the SDGs. Source: Authors' investigation.

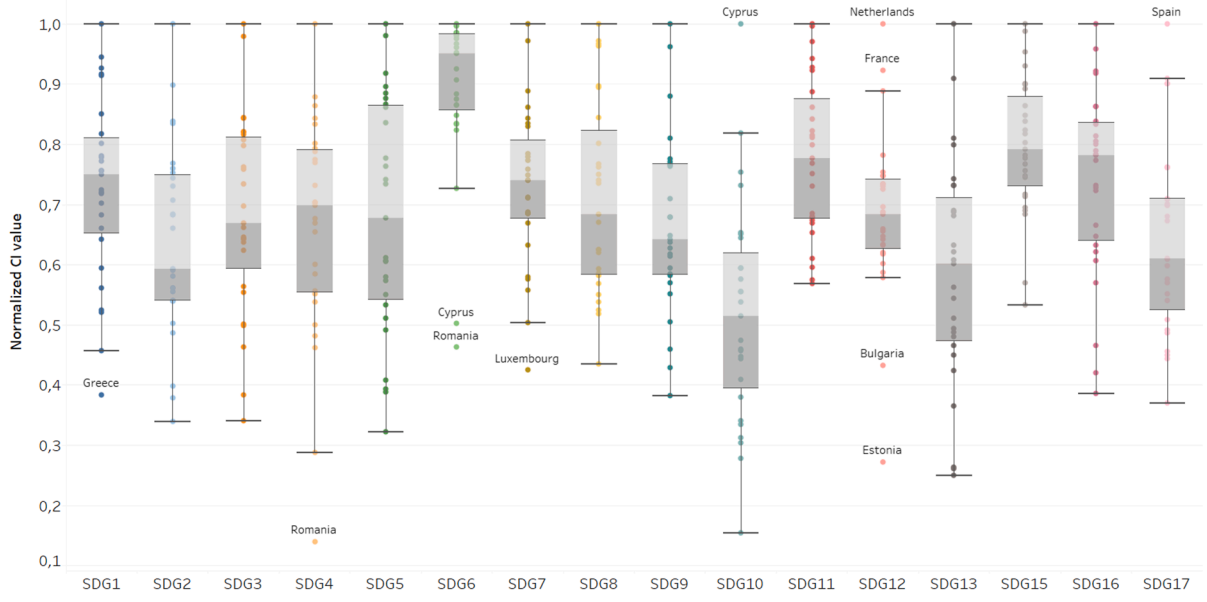

Fig. A1. A box-and-whisker plot for the composite indicator value for each of the SDGs. Source: Authors' investigation.

of the implementation of SDGs. Among the various methods of SDGs quantification, the ranking of countries is one of the most popular (Elavarasan et al., 2022; Cheba and Bąk, 2021; Miola and Schiltz, 2019; European Commission, 2022; Sompolska-Rzechuła and Kurdyś-Kujawska, 2021; 2022; Szopik-Depczyńska et al., 2018).

Our research unveils that Scandinavian countries often occupy the leading positions in individual SDGs' realisation. Sweden deserves special attention, as it most often occupies the top of the rankings. Many studies emphasise Sweden's position as a leader in achieving SDGs (European Commission, 2022; Miola and Schiltz, 2019; Szopik-Depczyńska et al., 2018). Another country that stands out in implementing the SDGs is the Netherlands, which occupies the leading position in SDG9, 12 and 17. The Netherlands, under SDG9, promote sustainable innovation and investment, particularly eco-innovation: a bio-based, circular economy and electric transport (European Environment Agency, 2020). Due to the existing problem related to renewable and green energy use, research works are devoted to implementing SDG7 and the indicators associated with this goal. Our research indicated that Denmark is the leader in this area, followed by Ireland and Sweden, while Luxembourg, Bulgaria and Cyprus are at the bottom. Slightly different results are presented in the work of Elavarasan et al. (2022) – Iceland, Norway and Sweden are the countries that performed best in SDG7, while Cyprus, Poland and Luxembourg took the last position. Denmark, the leader in our study, came fourth. It should be emphasised

Table A1
The 17 sustainable development goals.

SDG	Short title	Description	Number of targets
1.	No poverty	End poverty in all its manifestations, including extreme poverty, over the next 15 years. It envisions shared prosperity, basic standard of living and social protection benefits for people everywhere, including the poorest and most vulnerable	7
2.	Zero hunger	End hunger and malnutrition, and ensure access to safe, nutritious and sufficient food	8
3.	Good health and well-being	Ensure health and well-being for all at all ages by improving reproductive, maternal and child health; ending the epidemics of major communicable diseases; reducing non-communicable and mental diseases	13
4.	Quality education	Ensure access to equitable and quality education through all stages of life	10
5.	Gender equality	Achieving gender equality by ending all forms of discrimination, violence, and any harmful practices against women and girls in the public and private spheres	9
6.	Clean water and sanitation	Safe and affordable drinking water, sanitation and hygiene, and ending open defecation	8
7.	Affordable and clean energy	Ensuring universal access to modern energy services, improving energy efficiency and increasing the share of renewable energy	5
8.	Decent work and economic growth	Providing opportunities for full and productive employment and decent work for all while eradicating forced labour, human trafficking and child labour and promoting labour rights and safe and secure working environments	12
9.	Industry, innovation, and infrastructure	Building resilient and sustainable infrastructure, which supports sustainable development and human well-being	8
10.	Reduced inequalities	Reducing inequalities based on income, sex, age, disability, race, class, ethnicity, religion and opportunity by adopting relevant policies and legislation	10
11.	Sustainable cities and communities	Renew and plan cities and other human settlements in a way that they offer opportunities for all, with access to basic services, energy, housing, transportation, green public spaces, while improving resource use and reducing environmental impacts	10
12.	Responsible consumption and production	Action on all fronts: adoption of sustainable practices and sustainability reporting by businesses; promotion of sustainable procurement practices and rationalisation inefficient fossil-fuel subsidies by policy-makers; environmentally-aware lifestyles of consumers; development of new technologies and production and consumption methods by researchers and scientists and others	11
13.	Climate action	Strengthen countries' resilience and adaptive capacity to climate-related hazards and natural disasters by integrating climate change mitigation and adaptation measures into national strategies, policies and planning	5
14.	Life below water	Conserve oceans by ensuring their sustainable use. This includes the safeguarding of marine and coastal ecosystems, conserving at least 10 % of coastal and marine areas as well as preventing and reducing marine pollution and the impacts of ocean acidification	10
15.	Life on land	Protect, restore and promote the conservation and sustainable use of terrestrial, inland water and mountain 12ecosystems	12
16.	Peace, justice and strong institutions	Peaceful and inclusive societies based on respect for human rights, protection of the most vulnerable, the rule of law and good governance at all levels	12
17.	Partnerships for the goals	Universal, rules-based, open, non-discriminatory and equitable multilateral trading system under WTO and the implementation of duty-free and quota-free market access for all least developed countries	19

Source: own study based on Eurostat (2022).

that Elavarasan et al. (2022) used other indicators and methods to evaluate SDG7 implementation. Despite methodological differences, the results partially coincide with the results obtained in our study, showing regularities in the performance of the seventh SDG. In the research of Dmytrów et al. (2022), Norway was the best implementer of SDG7, and Denmark occupied leading positions in 2005, 2009 and 2020. Comparable results regarding the SDG7 execution were obtained by Cheba and Bąk (2021).

Since the announcement of the 2030 Agenda, most countries have achieved tremendous success in implementing SDGs 12, 10 and 13 (Sebestyén and Abonyi, 2021). Our research demonstrates analogous regularity. Our analysis reveals a certain regularity; the leaders are usually from countries with stronger economies (Scandinavian countries, Germany, France, Netherlands, Ireland, Belgium and Austria). Therefore, even if they rank lower in some SDGs, their socio-economic potential will be conducive to catching up quickly. Marti and Puertas (2020) show that few countries have improved all aspects of sustainable development and that economic growth is sometimes associated with social progress and environmental deterioration. Moreover, they argue that countries with ample natural wealth have precarious social and economic situations.

As it was mentioned, SDGs constitute an 'indivisible whole'. Therefore the interactions between goals should be well understood (Scharlemann et al., 2020). Our results align with Pradhan et al., 2017 and Yang et al., 2020 and emphasise more synergies than trade-offs within the SDGs (synergies were 34.2 % of all interactions). The goals with the utmost synergies are SDG 5, 6, 8, 3 and 16, while SDG7 is the only one not significantly related to others. Awareness of synergies can be used for Agenda 2030 strategy implementation, as improved performance in one of the goals may accelerate improvement in others.

Gender equality (SDG 5) is a fundamental human right and a necessary foundation for a peaceful, prosperous and sustainable world (United Nations. Sustainable, 2022; Eden and Wagstaff, 2021). In EU countries, high discrimination against women is relatively low, but actions for equality are constantly carried out. Access to clean water and decent work are basic human needs (SDGs 6 and 8). In developed economies, further growth must be related to the care of clean water: reduction of pollution, elimination of landfills, limitation of the use of

Table A2
Descriptive characteristics of indicators analysed in the paper.

Goal/Indicators	Eurostat code	Mean	Median	Min	Max	C.V.	S
Goal 1							
People living in households with very low work intensity, by age group (D)	SDG_01_40	7.38	7.20	3.90	12.30	34.50	0.35
In work at-risk-of-poverty rate (D)	SDG_01_41	7.86	7.80	3.10	14.90	35.11	0.45
Housing cost overburden rate by poverty status (D)	SDG_01_50	7.25	5.90	1.90	33.30	83.07	3.38
Self-reported unmet need for medical examination and care by sex (D)	SDG_03_60	2.31	1.60	0.00	13.00	119.89	2.50
Severe housing deprivation rate by poverty status (D)	SDG_11_11	4.21	3.10	1.00	14.30	79.13	1.56
Goal 2							
Obesity rate by body mass index (BMI) (D)	SDG_02_10	55.15	55.90	45.70	64.80	9.00	0.00
Government support for agricultural research and development (S)	SDG_02_30	6.26	5.10	0.40	18.70	71.12	1.27
Harmonised risk indicator for pesticides (HRI1) (D)	SDG_02_51	82.63	77.00	38.00	149.00	35.01	0.94
Ammonia emissions from agriculture (D)	SDG_02_60	25.49	20.60	7.20	105.30	81.53	2.50
Goal 3							
Healthy life years at birth by sex (S)	SDG_03_11	62.40	62.50	53.40	72.70	7.3	0.21
Share of people with good or very good perceived health by sex (S)	SDG_03_20	68.10	69.90	44.30	83.70	13.80	−0.87
Smoking prevalence by sex (D)	SDG_03_30	24.60	25.00	7.00	42.00	31.46	0.03
Self-reported unmet need for medical examination and care by sex (D)	SDG_03_60	2.30	1.60	0.00	13.00	119.89	2.50
Obesity rate by body mass index (BMI) (D)	SDG_02_10	55.15	55.90	45.70	64.80	9.00	0.00
Fatal accidents at work per 100 000 workers by sex (D)	SDG_08_60	2.00	2.01	0.48	3.50	44.42	0.10
Goal 4							
Early leavers from education and training by sex (D)	SDG_04_10	8.68	8.10	2.20	16.00	39.53	0.41
Tertiary educational attainment by sex (S)	SDG_04_20	43.38	43.70	24.90	60.60	21.16	0.02
Participation in early childhood education by sex (S)	SDG_04_31	90.29	91.70	71.30	100.00	8.04	−1.04
Adult participation in learning (S)	SDG_04_60	10.06	7.70	1.00	28.60	71.90	1.18
Share of individuals having at least basic digital skills (S)	SDG_04_70	56.26	55.00	28.00	79.00	21.46	−0.30
Goal 5							
Inactive population due to caring responsibilities by sex (D)	SDG_05_40	24.44	22.90	4.50	54.20	55.48	0.64
Positions held by women in senior management positions (S)	SDG_05_60	25.00	26.20	8.80	45.10	43.40	−0.02
Early leavers from education and training by sex (D)	SDG_04_10	8.68	8.10	2.20	16.00	39.53	0.41
Tertiary educational attainment by sex (S)	SDG_04_20	43.38	43.70	24.90	60.60	21.16	0.02
Goal 6							
Population having neither a bath, nor a shower, nor indoor flushing toilet in their household by poverty status (D)	SDG_06_10	1.93	0.40	0.00	21.20	227.30	3.62
Water exploitation index, plus (WEI +) (D)	SDG_06_60	9.61	4.15	0.22	70.30	158.37	2.90
Goal 7							
Primary energy consumption (D)	SDG_07_10	2.88	2.63	1.44	6.25	37.31	1.60
Energy productivity (S)	SDG_07_30	7.87	6.77	2.47	22.61	54.71	1.91
Share of renewable energy in gross final energy consumption by sector (S)	SDG_07_40	24.36	21.22	10.71	60.12	47.09	1.41
Energy import dependency by products (D)	SDG_07_50	58.02	56.63	10.50	97.56	36.42	0.00
Population unable to keep home adequately warm by poverty status (D)	SDG_07_60	7.81	5.70	1.50	27.50	91.42	1.54
Goal 8							
Investment share of GDP (S)	SDG_08_11	22.31	21.85	11.66	39.68	23.03	1.29
Long-term unemployment rate (D)	SDG_08_40	2.29	1.80	0.60	10.50	87.03	3.05
Fatal accidents at work per 100 000 workers (D)	SDG_08_60	1.97	2.01	0.48	3.53	44.42	0.10
In work at-risk-of-poverty rate (D)	SDG_01_41	7.86	7.80	3.10	14.90	35.11	0.45
Inactive population due to caring responsibilities (D)	SDG_05_40	24.44	22.90	4.50	54.20	55.48	0.64
Goal 9							
Gross domestic expenditure on R&D by sector (S)	SDG_09_10	1.78	1.53	0.47	3.53	51.59	0.59
Share of rail and inland waterways in inland freight transport (S)	SDG_09_60	27.85	26.20	0.80	64.70	61.92	0.41
Air emission intensity from industry (D)	SDG_09_70	0.17	0.06	0.01	0.84	132.55	2.29
Tertiary educational attainment by sex (S)	SDG_04_20	43.38	43.70	24.90	60.60	21.16	0.02
High-speed internet coverage, by type of area (S)	SDG_17_60	65.14	67.10	10.20	100.00	36.07	−0.52
Goal 10							
Purchasing power adjusted GDP per capita (S)	SDG_10_10	30781.48	26500.00	16400.0	78700.00	43.80	2.25
Income distribution (D)	SDG_10_41	4.72	4.48	3.03	8.01	23.99	1.06
Asylum applications (S)	SDG_10_60	1172.19	381.00	9.00	7920.00	149.64	2.69
People at risk of poverty or social exclusion (D)	SDG_01_10A	19.18	19.00	7.50	28.30	26.90	−0.29
Early leavers from education and training (D)	SDG_04_10A	7.71	7.40	2.10	15.60	42.69	0.66
Employment rate (S)	SDG_08_30A	74.29	75.10	61.60	83.40	7.20	−0.70

(*continued on next page*)

Table A2 (*continued*)

Goal/Indicators	Eurostat code	Mean	Median	Min	Max	C.V.	S
Goal 11							
Severe housing deprivation rate by poverty status (D)	SDG_11_11	4.21	3.10	1.00	14.30	79.13	1.56
Population living in households considering that they suffer from noise, by poverty status (D)	SDG_11_20	16.04	14.70	8.00	30.80	35.77	0.69
Road traffic deaths (D)	SDG_11_40	4.54	4.30	2.00	8.500	35.00	0.63
Years of life lost due to PM2.5 exposure (D)	SDG_11_51	749.33	641.00	258.00	1606.00	45.48	0.67
Recycling rate of municipal waste (S)	SDG_11_60	39.57	39.60	10.50	67.00	36.43	−0.20
Population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames of floor by poverty status (D)	SDG_01_60	14.07	12.50	4.50	39.10	53.12	1.42
Share of buses and trains in inland passenger transport (S)	SDG_09_50	17.95	17.30	9.40	28.40	23.59	0.74
Population reporting occurrence of crime, violence or vandalism in their area by poverty status (D)	SDG_16_20	9.23	8.30	2.40	19.10	50.54	0.69
Goal 12							
Average CO2 emissions per km from new passenger cars (D)	SDG_12_30	111.14	113.00	82.30	133.00	10.38	−0.53
Circular material use rate (S)	SDG_12_41	10.19	7.90	1.30	30.90	73.21	1.13
Generation of waste excluding major mineral wastes by hazardousness (D)	SDG_12_50	2026.59	1579.00	701.00	9711.00	82.45	4.00
Energy productivity (S)	SDG_07_30	7.87	6.77	2.47	22.61	54.71	1.91
Goal 13							
Net greenhouse gas emissions (D)	SDG_13_10	8.21	7.40	1.80	19.70	43.98	1.23
Contribution to the international 100bn USD commitment on climate related expending (S)	SDG_13_50	1.89	0.12	0.00	9.95	153.92	1.68
Population covered by the Covenant of Mayors for Climate & Energy signatories (S)	SDG_13_60	44.82	47.80	7.30	92.70	46.51	0.22
Share of renewable energy in gross final energy consumption by sector (S)	SDG_07_40	24.36	21.22	10.71	60.12	47.09	1.41
Goal 15							
Share of forest area (S)	SDG_15_10	40.40	39.60	10.40	69.90	39.81	−0.12
Surface of the terrestrial protected areas (S)	SDG_15_20	27.27	26.60	13.20	51.50	38.10	0.44
Soil sealing index (D)	SDG_15_41	108.97	107.90	105.90	122.90	3.16	2.79
Estimated soil erosion by water - area affected by severe erosion rate (D)	SDG_15_50	4.95	2.63	0.00	24.93	128.35	1.81
Goal 16							
Standardised death rate due to homicide (D)	SDG_16_10	0.93	0.72	0.28	3.32	71.63	2.26
Population reporting occurrence of crime, violence or vandalism in their area by poverty status (D)	SDG_16_20	9.23	8.30	2.40	19.10	50.54	0.69
Corruption Perceptions Index (S)	SDG_16_50	63.67	60.00	44.00	88.00	22.32	0.25
Population with confidence in EU institutions by institution (S)	SDG_16_60	52.81	55.00	36.00	79.00	20.47	0.28
Goal 17							
EU imports from developing countries by country income groups (S)	SDG_17_30	186.02	128.83	76.19	931.00	92.49	3.53
General government gross debt (S)	SDG_17_40	75.36	59.70	19.00	206.30	58.47	1.24
Share of environmental taxes in total tax revenues (D)	SDG_17_50	6.71	6.76	3.62	9.89	24.80	0.26
High-speed internet coverage, by type of area (S)	SDG_17_60	65.14	67.10	10.20	100.00	36.07	−0.52

Source: Authors' investigation, where S – stimulants, D – destimulants.

harmful chemicals, and restriction of water used in production. Economic growth should also favour access to good jobs, eradicate poverty, increase welfare and enhance appropriate consumption, but without harming the environment. According to Zurlini and Müller (2008), the relationship between the environment and security is now prevalent among scientific and policy communities.

Reducing poverty (SDG 1) is as important as lowering disparities (mainly within countries). However, the cake of economic growth is often shared among the wealthiest inhabitants (Lakner et al., 2019; Mansi et al., 2020). To facilitate poverty reduction, every citizen should benefit from economic progress. Economic activity must bring financial profits and benefits for people and the environment (Ekins and Zenghelis, 2021). However, there is a need to raise awareness and increase cooperation among supply chain members. An educated society is the basis for building a stable infrastructure, sustainable industrialisation and innovation. Such society incentives the development of ICTs and highly advanced technologies boosting productivity.

When people pursue their aspirations to satisfy hunger, create living conditions, and increase consumption and welfare, they tend to ignore or underestimate the care for the natural environment (Osuntuyi and Lean, 2022). The necessity of actions aimed at reducing environmental degradation, maintaining biodiversity, protecting ecosystems, shielding endangered animals and plants, and abolishing invasive alien species is indicated. However, these activities require resources that could be allocated to other purposes. Hence the competition between SDG15 and SDG3, i.e. improvement in health care. The COVID-19 pandemic has undoubtedly only deepened these animosities. The pandemic also shifted interest and resources from SDG15 to SDG17. The partnership for sustainable development at that time required a particular focus on the ICT sector. The prospects for achieving the 2030 Sustainable Development Goals have deteriorated significantly since the COVID-19 pandemic spread worldwide in early 2020 (Eden and Wagstaff, 2021). According to Chakraborty and Maity (2020), the pandemic has spread around the world and has created enormous health, economic, environmental and social challenges. The authors emphasise the negative economic impact: limiting production and transport and increasing healthcare spending. But at the same time, they indicate the positive effect of the economic slowdown on the natural environment. Espejo et al. (2020) also write about the links between the natural environment and health conditions. Lack of care for the environment may harm the health of society and, at the same time, facilitate the spread of the pandemic. Lekagul et al. (2022) indicate the negative impact of the

Table A3
Indicators used in the study and their assigned weights.

Goal		Indicator	Weight
1.	No poverty	SDG_01_40	0.3258
		SDG_01_41	0.1940
		SDG_01_50	0.0342
		SDG_03_60	0.1667
		SDG_11_11	0.2793
2.	Zero hunger	SDG_02_10	0.2422
		SDG_02_30	0.2775
		SDG_02_51	0.3608
		SDG_02_60	0.1196
3.	Good health and well-being	SDG_03_11	0.0831
		SDG_03_20	0.1089
		SDG_03_30	0.1886
		SDG_03_60	0.3081
		SDG_02_10	0.1411
		SDG_08_60	0.1702
4.	Quality education	SDG_04_10	0.4341
		SDG_04_20	0.0433
		SDG_04_31	0.4576
		SDG_04_60	0.0383
		SDG_04_70	0.0267
5.	Gender equality	SDG_05_40	0.3639
		SDG_05_60	0.0958
		SDG_04_10	0.3196
		SDG_04_20	0.2207
6.	Clean water and sanitation	SDG_06_10	0.5097
		SDG_06_60	0.4903
7.	Affordable and clean energy	SDG_07_10	0.3304
		SDG_07_30	0.2307
		SDG_07_40	0.1609
		SDG_07_50	0.0886
		SDG_07_60	0.1894
8.	Decent work and economic growth	SDG_08_11	0.2505
		SDG_08_40	0.2085
		SDG_08_60	0.2490
		SDG_01_41	0.1176
		SDG_05_40	0.1744
9.	Industry, innovation and infrastructure	SDG_09_10	0.1266
		SDG_09_60	0.3073
		SDG_09_70	0.2424
		SDG_04_20	0.2084
		SDG_17_60	0.1153
10.	Reduced inequalities	SDG_10_10	0.2248
		SDG_10_41	0.0222
		SDG_10_60	0.3255
		SDG_01_10	0.1866
		SDG_04_10	0.0245
		SDG_08_30	0.2165
11.	Sustainable cities and communities	SDG_11_11	0.1375
		SDG_11_20	0.2273
		SDG_11_40	0.0597
		SDG_11_51	0.1356
		SDG_11_60	0.0493
		SDG_01_60	0.1861
		SDG_09_50	0.1177
		SDG_16_20	0.0868
12.	Responsible consumption and production	SDG_12_30	0.0482
		SDG_12_41	0.3698
		SDG_12_50	0.4585
		SDG_07_30	0.1235
13.	Climate action	SDG_13_10	0.2423
		SDG_13_50	0.3406
		SDG_13_60	0.3203
		SDG_07_40	0.0969
15.	Life on land	SDG_15_10	0.1988
		SDG_15_20	0.2339
		SDG_15_41	0.3327
		SDG_15_50	0.2346
16.	Peace, justice and strong institutions	SDG_16_10	0.4151
		SDG_16_20	0.2660
		SDG_16_50	0.1557
		SDG_16_60	0.1631
17.	Parthership and future goals	SDG_17_30	0.1834
		SDG_17_40	0.3397
		SDG_17_50	0.1845
		SDG_17_60	0.2924

Source: Authors' investigation.

Covid-19 pandemic on the implementation of SDGs in the field of 'People' and 'Prosperity'. However, the effect on 'Planet' is both positive and negative. They also point out that the pandemic has exposed countries' weaknesses in 'Peace' and 'Partnership'.

Pradhan et al., 2017; Warchold et al., 2021 and Zhang et al., 2022, indicated both synergies and compromises for SDG7, while in our study, these turned out to be statistically insignificant. Notwithstanding, the energy sector is considered an indispensable factor in the country's economic development (Bieszk-Stolorz & Markowicz, 2021). The literature emphasises that growing energy demand correlates with sustainable economic development and ecological balance (Omer, 2009; Bologna, 2013). Renewable energy usage contributes to reducing dependence on fossil fuels. Innovative renewable applications and a stronger renewable energy market will preserve the ecosystem. From an economic point of view, renewable energy systems usually have a high initial investment and low operating costs. However, these investments are necessary to prevent glitches related to the energy needs of people and enterprises. Unfortunately, energy problems (demand, prices, shortage of raw materials) are evolving, especially in times of crisis (Bieszk-Stolorz & Markowicz, 2022). Energy from renewable natural resources (wind, sun, water) is mean and independent of crises. It is, therefore, necessary to intensify investments in clean energy, which is needed by the global economy and humanity.

6. Conclusion

Our research aligns with the discussion on interactions and SDGs realisation, extending it with a new methodological approach. National policymakers face the challenge of meeting the goals by 2030. However, simultaneously accomplishing a progress in the economic, social and environmental dimensions is not straightforward. It turns out that there is a need to define the urgency of the challenges (Griggs et al., 2017). Therefore, the importance of research is emphasised, as it may support policy-makers in the implementation, sequencing and monitoring of SDGs. Our study concerned the EU countries in 2020. The designated CI with weights equalising the importance of the variables allowed us to determine the rankings of countries in terms of achieving individual goals. It turned out that the more developed countries (with high economic indicators) occupied the leading positions in almost all ranks. We identified 41 synergies and two trade-offs. Our research confirms the advantage of synergy over compromises, which aligns with previous research. SDG5 has the highest number of relationships with goals from all areas (People, Planet, Prosperity, Peace and Partnership), which confirms that the SDGs are reinforcing each other.

The goals positively correlated with many others are: SDG6 - clean water and sanitation and SDG8 - decent work and economic growth. The research also shows that responsible consumption and production implementation may affect the execution of indicators related to hunger and climate. Our results confirm the necessity of cooperation between government, private enterprises and civil society. Another important lesson is that high-quality education is the basis for improving people's lives and sustainable development.

We attach particular importance to two research conclusions:

(i) Significant negative interactions between SDG15 & 3 and SDG15 & 17. These goals compete with each other. Care for the natural environment probably took a back seat during the COVID-19 pandemic, and medical care spending and ICTs development were of greater importance.
(ii) No significant linkage between SDG7 (affordable and clean energy) and other goals.

The problem of clean and cheap energy is still pressing. Investments

in clean energy are a must all over the world. Energy problems (demand, prices, carbon footprint and environmental impact) are highlighted in times of crisis (COVID-19 pandemic, war in Ukraine).

We believe that more research on sustainability is needed. The focus should be a punt on interdisciplinary research, i.e. synergy of knowledge from economics, natural sciences, engineering, ecology, etc.

7. Data availability statement

The data used in the study were taken from: https://ec.europa.eu/eurostat/web/sdi/database (accessed on: 04 July 2022).

CRediT authorship contribution statement

Marta Kuc-Czarnecka: Conceptualization, Data curation, Investigation, Writing – original draft, Writing – review & editing, Data curation, Formal analysis, Methodology, Software, Visualization. **Iwona Markowicz:** Conceptualization, Data curation, Investigation, Writing – original draft, Writing – review & editing, Resources. **Agnieszka Sompolska-Rzechuła:** Resources, Conceptualization, Data curation, Investigation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

publicly available data from the Eurostat database

Appendix A

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