Sustainability assessment of EU Countries towards 2030 Agenda with MCDA-GIS integrated approach

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1. Introduction

Agenda 2030, is an action plan for peace, people, planet and prosperity adopted by all member states of the United Nations in 2015 who, acting in partnership, are continuing to pursue it.[1] In this context, the 17 Sustainable Development Goals (SDGs) that make up the Agenda have acquired a key role in the scientific literature and many studies have focused on measuring progress at various scales in terms of achieving the goals.
Indeed, studies on the assessment of the level of sustainability are crucial, as they enable decision-makers to make well-considered choices, to be effective in terms of actions and policies, and to give attention to sustainability measures. Understanding the different factors, social, environmental and economic, that influence sustainability allows policy-makers to identify areas for intervention and strategies to be implemented where they are needed most.[2] Since it is a multidimensional concept, the measurement of sustainability is complex, as it covers social, environmental, economic and also institutional issues. Composite or aggregate indicators seem to be a useful tool in this context, as they combine a set of indicators selected to express the most of characteristics and aspects of a complex phenomenon. [3]
The objective of this paper is to assess the level of sustainable development achieved by the 27 EU Member States through a set of 77 indicators selected from the Eurostat database, which consider the environmental, economic, social and institutional dimensions of each country, with reference to the 2030 Agenda. The Spatial Sustainability Assessment Model (SSAM) was used, it is a tool that perform multi-criteria analysis integrated in the geographical tool Quantum GIS.

2. Materials and methods

The study is based on the multi-criteria analysis methodology which allows the assessments of several aspects at the same time, integrated and combined together. This characteristic is ideal for the assessment of sustainable development because, being a multi-dimensional concept, it integrates multiple aspects from different areas. In this case, the dimensions involved are the environmental, economic, social and

[1] An Baeyens and Tom Goffin, "European Court of Justice," *European Journal of Health Law* 22, no. 5 (2015): 508–16, https://doi.org/10.1163/15718093-12341375.
[2] Antonio Boggia et al., "Spatial Multicriteria Analysis for Sustainability Assessment: A New Model for Decision Making," *Land Use Policy* 71 (February 1, 2018): 281–92, https://doi.org/10.1016/J.LANDUSEPOL.2017.11.036.
[3] "Handbook on Constructing Composite Indicators: Methodology and User Guide," *Handbook on Constructing Composite Indicators: Methodology and User Guide*, 2008, https://doi.org/10.1787/9789264043466-en.

institutional ones. In each of these dimensions, there are different indicators that need to be combined to express different aspects and situations; for this reason, they are divided and aggregated into sub-dimensions according to the related theme.

2.1. Indicators

In this study, in order to assess the sustainable development of EU member states, the indicators were selected from the Eurostat database, the statistical office of the European Union. The SDGs dataset for the EU includes those indicators that are relevant in the European context and therefore allows the monitoring of progress towards the goals in the long-term EU policy perspective. The data are referred to the year 2020 and they were downloaded in March 2022. The criteria for the selection of the indicators were:
- the availability of data for the 27 countries considered;
- the availability of data for the years considered;
- the avoidance of redundant or overlapping indicators;
- the representativeness of the topic of the concerned dimension.

For some indicators, data were not available for 2020, so those of 2019 were selected or those from the closest available year; the same procedure was also used for individual states lacking data for a specific indicator.
Once all indicators were selected, an analysis to investigate the presence of possible anomalous values for all countries was conducted. As in [4] study, the outlier detection was made through the interquartile range (IQR = Q3 −Q1) method. [5] According to this test, two different outliers can be detected: mild outliers (Q1 - 1.5 - IQR; Q3 + 1.5 - IQR) and extreme outliers (Q1 - 3 - IQR; Q3 + 3 - IQR). In this case, mid outliers were not considered. Instead, extreme outliers were taken into account, assigning to the corresponding result function, the minimum or maximum value (depending on relative position) of the scale.
The total number of selected indicators is 77, divided into the 4 dimensions of sustainability and the sub-dimensions, as shown in Table 1.

SOCIAL	
POVERTY	**HEALTH and WELLBEING**
People at risk of poverty or social exclusion (1_10)	Healthy life years at birth (3_11)
People at risk of income poverty after social transfers (1_2)	Share of people with good or very good perceived health (3_2)
Severely materially deprived people (1_3)	Smoking prevalence (3_3)
People living in households with very low work intensity (1_4)	Self-reported unmet need for medical examination and care (3_6)
Population living in a dwelling with a leaking roof, damp walls, floors or foundation or rot in window frames of floor (1_6)	Obesity rate by body mass index (BMI) (2_1)
Population unable to keep home adequately warm (7_6)	Overcrowding rate (11_10)

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[4] Samira El Gibari et al., "Analyzing the Impact of Spanish University Funding Policies on the Evolution of Their Performance: A Multi-Criteria Approach," *Mathematics 2021, Vol. 9, Page 1626* 9, no. 14 (July 9, 2021): 1626, https://doi.org/10.3390/MATH9141626.
[5] J W Tukey, "Exploratory Data Analysis," *Addison-Wesley: Boston, MA, USA; ISBN 9780201076165.*

In work at-risk-of-poverty rate (1_41)	Population living in households considering that they suffer from noise (11_2)
Population having neither a bath, nor a shower, nor indoor flushing toilet in their household (6_10)	**EQUALITY**
EDUCATION	Gender pay gap in unadjusted form (5_2)
Early leavers from education and training (4_10)	Gender employment gap (5_3)
Tertiary educational attainment (4_20)	Positions held by women in senior management positions (5_6)
Participation in early childhood education (children aged 3 and over) (4_31)	Seats held by women in national parliaments and governments (5_5)
Adult participation in learning (4_6)	Inactive population due to caring responsibilities by sex (5_4)
Share of individuals having at least basic digital skills (4_7)	Relative median at-risk-of-poverty gap (10_3)
Young people neither in employment nor in education and training (NEET) (8_2)	Income distribution (10_41)
Gross domestic expenditure on R&D (Higher Education Sector) (9_1)	Asylum applications (10_6)
R&D personnel by Higher Education Sector (9_3)	**SERVICES**
WORK	High-speed internet coverage, by type of area (17_6)
People killed in accidents at work (8_6)	**SAFETY**
Employment rate (8_3)	Road traffic deaths, by type of roads (11_4)
Long-term unemployment rate (8_4)	Population reporting occurrence of crime, violence or vandalism in their area (16_2)
ENVIRONMENTAL	**ECONOMIC**
LAND	**AGRICULTURE**
Area under organic farming (2_4)	Agricultural factor income per annual work unit (AWU) (2_2)
Harmonised risk indicator for pesticides (HRI1), by groups of active substances (2_51)	Government support to agricultural research and development (2_3)
Surface of terrestrial sites designated under Natura 2000 (15_2)	**PRODUCTIVITY and INCOME**
CLIMATE	Real GDP per capita (8_1)
Ammonia emissions from agriculture (2_6)	Investment share of GDP by institutional sectors (8_11)
Exposure to air pollution by particulate matter (11_5)	Income share of the bottom 40 % of the population (10_5)
Average CO2 emissions per km from new passenger cars (12_3)	Adjusted gross disposable income of households per capita (10_2)
Greenhouse gas emissions by source sector (13_1)	Energy productivity (7_3)
Greenhouse gas emissions intensity of energy consumption (13_2)	**R&D (Research and Development)**
ENERGY	Gross domestic expenditure on R&D by sector (9_10)
Primary energy consumption (7_1)	R&D personnel by sector (9_3)
Final energy consumption (7_11)	Patent applications to the European Patent Office (9_4)
Share of renewable energy in gross final energy consumption by sector (7_4)	**INSTITUTIONAL**
CIRCULAR ECONOMY	**CONFIDENCE IN INSTITUTIONS**

Recycling rate of municipal waste (11_6)	Perceived independence of the justice system (16_4)
Resource productivity and domestic material consumption (DMC) (12_2)	Corruption Perceptions Index (16_5)
Circular material use rate (12_41)	Population with confidence in EU institutions by institution (16_6)
MOBILITY	**EXPENDITURE AND DEBTS**
Share of buses and trains in total passenger transport (9_5)	General government total expenditure on law courts (16_3)
POLICY	General government gross debt (17_4)
Contribution to the international 100bn USD commitment on climate related expending (13_5)	Investment share of GDP by institutional sectors (GOVERNMENT INVESTMENT) (8_11)
Population covered by the Covenant of Mayors for Climate & Energy signatories (13_6)	Gross domestic expenditure on R&D by sector (GOVERNMENT SECTOR) (9_10)
Share of environmental taxes in total tax revenues (17_5)	R&D personnel by sector (GOVERNMENT SECTOR) (9_3)
WATER	**COOPERATION**
Surface of marine sites designated under Natura 2000 (14_1)	Official development assistance as share of gross national income (17_1)
INLAND Bathing sites with excellent water quality by locality (14_4)	
Marine waters affected by eutrophication (14_6)	

Table 1: Indicators and their division into sub-dimensions and dimensions

2.2. Weighting

In this study a weighting system with experts was applied. On the basis of their experience in the field and their background, three experts for each of the 4 sustainability dimensions considered (social, economic, environmental and institutional) were selected. They fulfil a questionnaire assessing the importance of each sub-dimension within each dimension and of each indicator within each sub-dimension using a Likert scale between 0 and 5 (0 not important; 5 extremely important). The weights of 3 different experts were then obtained for each dimension.

As pointed out previously, the majority of decisional problems have a multi-criteria nature, as they have to consider simultaneously different criteria and multi-disciplinary indicators. Most of the multi-criteria methods require a judgement of value from the decision maker on various aspects (such as weights for criteria, pairwise comparisons between criteria or alternatives, trade-off rates between objective functions, target values, benchmarks or reference values), in order to determine the relative importance of the criteria. In addition, there is a further complication that arises when the opinions of different social groups with different perspectives on these judgements have to be considered simultaneously. This problem is generally known as a group decision problem. [6] The problem of group decision making can be found also in this case, since the judgements of the various experts with different ideas have to be considered simultaneously establishing a common value. To solve this preference aggregation problem, we used the meta-objective programming approach. [7] The objective of the methodology is precisely to aggregate individual judgements value on different

[6] Amalia Benítez-Fernández and Francisco Ruiz, "A Meta-Goal Programming Approach to Cardinal Preferences Aggregation in Multicriteria Problems," *Omega (United Kingdom)* 94 (2020), https://doi.org/10.1016/j.omega.2019.03.003.

[7] Amalia Benítez-Fernández and Francisco Ruiz. (2020)

preference elements by several individuals (DMs, stakeholders, etc.) involved in a certain decision-making process, to obtain social (group) value judgements, using Meta-GP (Meta Goal Programming). This method was used in order to calculate the weights for each indicator and sub-dimension. At the dimension level, on the other hand, the objective method was used: the average weight method[8], in order to assign equal importance to the different spheres, according to the principle of strong sustainability.

2.3. Spatial Sustainability Assessment Model (SSAM)

The assessment model used is SSAM (Spatial Sustainability Assessment Model), a tool that allows territorial sustainability assessments through the perfect integration of multi-criteria analysis with the geographical dimension, as a result of the updates over time. [9] [10] The assessment procedure through SSAM is carried out within a widely diffused open source GIS tool called QuantumGIS or QGIS, configuring itself as a *plugin*[11]. SSAM incorporates two multi-criteria algorithms: TOPSIS (Technique for Order Preference by Similarity to Ideal Design) and weighted sum. Through TOPSIS it is possible to aggregate the different criteria of each dimension by constructing composite indicators, one for each dimension. The composite indices obtained can be further aggregated to obtain an overall index, in this case using the weighted sum, which is useful to get a synthetic overview of the sustainability level. In this study, the TOPSIS algorithm was always used, instead of the weighted sum, in order to limit the loss of information in the three levels of aggregation. Therefore, each consecutive index from the first aggregation level was computed using the output of the previous aggregation level as input.

After the aggregation process, the results are presented for reading and interpretation, in the form of numerical values and in graphical format (maps, cartograms and charts). Numerical outputs can also be reorganised and processed directly in QGIS, providing more customised results.

SSAM is also provided with a so-called 'back analysis' procedure, capable of tracing the steps that led to the final result, revealing which indicators and/or procedural steps had the greatest influence on the results obtained. Through the use of this algorithm, a number of 'decision rules' are extracted in order to ensure transparency and monitor the results, going back from the final score to the input data.

2.4. The TOPSIS multi-criteria algorithm

The aggregation of several indicators in a single synthetic measure always implies some loss of information on the way. For this reason, this aggregation must be done in the most informative possible way, so that the results obtained can be easily interpreted, and in an efficient way. [12] [13] In this study, there are three levels of aggregation: the first is

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[8] Hepu Deng, Chung Hsing Yeh, and Robert J. Willis, “Inter-Company Comparison Using Modified TOPSIS with Objective Weights,” *Computers & Operations Research* 27, no. 10 (September 1, 2000): 963–73, https://doi.org/10.1016/S0305-0548(99)00069-6.

[9] Boggia et al., “Spatial Multicriteria Analysis for Sustainability Assessment: A New Model for Decision Making.”

[10] Lucia Rocchi et al., “Towards the 2030 Agenda: Measuring the Progress of the European Union Countries through the SDGs Achievement Index,” *Sustainability (Switzerland)* 14, no. 6 (2022), https://doi.org/10.3390/su14063563.

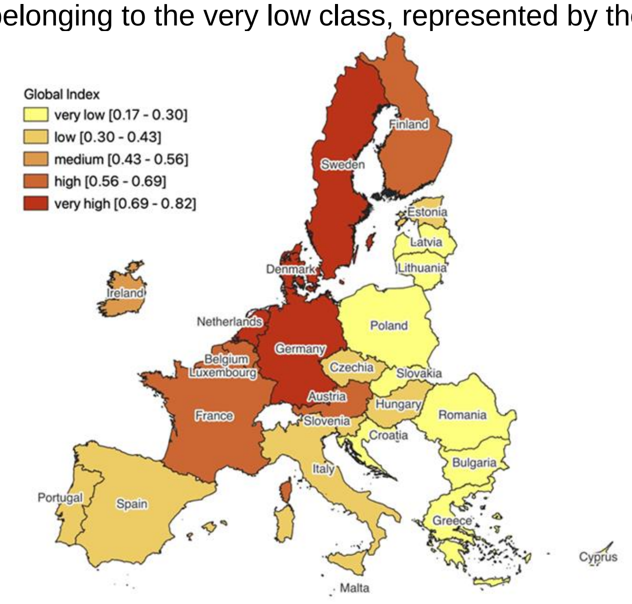
[11] A plugin is a non-autonomous programme that interacts with another programme to enlarge or extend its original functionality, allowing the use of new functions not present in the main software.

[12] Francisco Ruiz et al., “MRP-WSCI: Multiple Reference Point Based Weak and Strong Composite Indicators,” *Omega* 95 (September 1, 2020): 102060, https://doi.org/10.1016/J.OMEGA.2019.04.003.

among the 77 indicators selected within the sub-dimensions, the second concerns the latter in the four dimensions of sustainable development (economic, social, environmental and institutional) and the last refers to the global indicator of sustainability, created for each of the 27 states examined.
The multi-criteria algorithm used for all levels of aggregation is the TOPSIS Method or Ideal Point method (Technique for Order Preference by Similarity to Ideal Design)[14], which makes it possible to evaluate a set of alternatives on the basis of their distance from the ideal point. In particular, the method carries out an order on the basis of several criteria, setting an objective to strive towards (ideal point) and one to move away from (worst point) for each evaluation criterion. The ideal point therefore represents a hypothetical alternative that optimizes the value of each criterion, and can be found within the range of the proposed indicators or outside of it: in fact, the plugin allows absolute customization. For this work the best and worst alternatives are represented by the maximum and minimum values of each indicator, respectively, or vice versa, depending on whether it is an indicator to be maximized or minimized.

4. Results

The outputs resulting from the assessment model were processed and used to provide a clear and comprehensive picture of the level of the sustainable development achieved by the 27 countries analysed. One of the main outputs of SSAM are maps. Figure 1 shows the geographical distribution of the global sustainability index among the EU countries, without specifying the trend in the dimensions that compose the global index of each state. Through a colour grading within the map, countries are distributed on a scale of five classes ranging from very low to very high values of the index and with an interval for each class defined based on a QGIS function, namely the equal intervals algorithm. The best performing countries are those belonging to the very high class, represented by the darkest colour while the worst performing countries are those belonging to the very low class, represented by the lightest colour.



[13] Samira El Gibari et al., "Composite Indicators as Decision Making Tools: The Joint Use of Compensatory and Noncompensatory Schemes," *Https://Doi.Org/10.1142/S0219622021500231* 20, no. 3 (April 14, 2021): 847–79, https://doi.org/10.1142/S0219622021500231.
[14] Ching-Lai Hwang and Kwangsun Yoon, "Methods for Multiple Attribute Decision Making," 1981, 58–191, https://doi.org/10.1007/978-3-642-48318-9_3.

Figure 1: Global sustainability index map

Class 1 includes the countries with the best values for the global sustainability index, ranging between 0.69 and 0.82. In particular, they are Denmark, Germany, Luxembourg, the Netherlands and Sweden.
These states achieve a very high level for the social and economic dimensions (Figure 2) and also for the institutional sphere results are good, in fact they all have a value higher than 0.6. The worst results concern the environmental dimension, where the values for all states are less than 0.6, except for Germany which, however, slightly exceed this value. Luxembourg is the worst EU country for the environmental dimension.
In class 2, with high values (0.56 to 0.68), there are Austria, Belgium, Finland, France and Ireland. In the third class with medium values (0.43 to 0.55) there are only two countries, Czechia and Slovenia.
For the distribution analysis of the dimensions we have considered the two classes together (Figure 2) and it can be seen that for the social dimension the values are high for all countries, reaching a values around 0.7 and in many cases exceeding it. In the economic sphere there isn't a similar behaviour between the different states, in fact the Czechia and Slovenia have low values (less than 0.5), in contrast Finland has a high value (0.7).
The values of the institutional and environmental dimensions are in a lower range (below 0.6), with few exceptions like Finland for the institutional sphere with a value of 0.63 and France for the environmental sphere with a value of 0.72, achieving the best value among all EU countries.

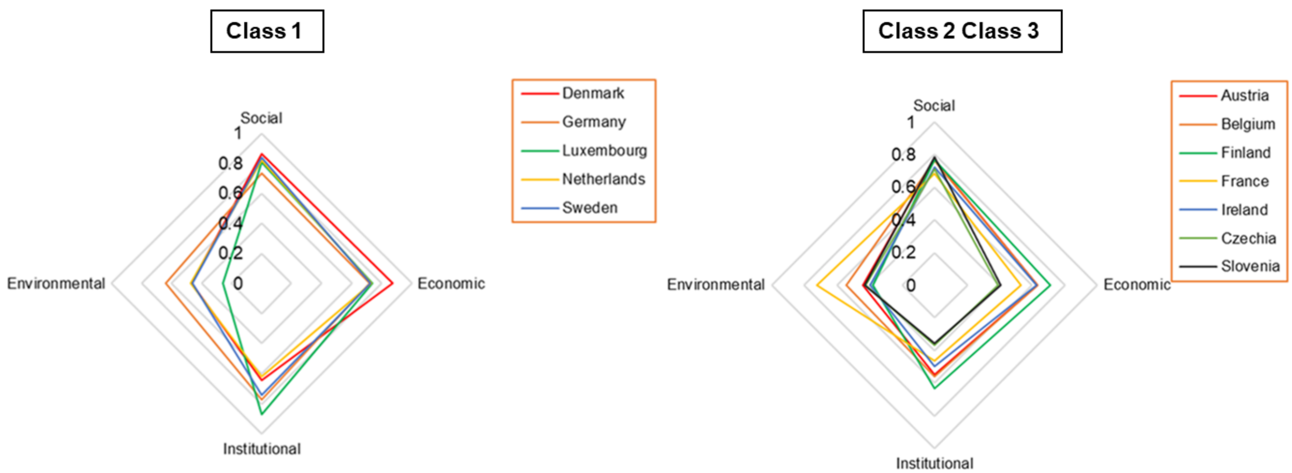


Figure 2: Dimension value distribution of class 1, 2 and 3

In the fourth class there are Croatia, Estonia, Hungary, Italy, Lithuania, Malta, Portugal, Spain with a global sustainability index value ranging from 0.30 to 0.43. For these countries, there is a significant reduction of the values of the economic and institutional sphere (Figure 3). In this last dimension, Portugal and Italy have the worst values, lower than 0.2. The social results are on the high average level for all countries and the environmental values are aligned with those of the upper classes analysed previously.
Class 5 is the one with the worst global sustainability index, with values ranging from 0.17 to 0.30, containing Bulgaria, Cyprus, Greece, Latvia, Poland, Romania and Slovakia. For these countries, the trend is very similar to class 4, but there is a further reduction in the values of the economic and social dimensions by several states (Figure

3). The results of the social dimension are not uniform across countries, in fact Poland achieves a very high value (0.73) and the worst result is achieved by Greece (0.27). Romania and Bulgaria are in the lowest position for the economic dimension.
For the environmental sphere, on the other hand, the values of the countries in this class remain stable and no significant decreases are observed in relation to the countries in the upper classes.

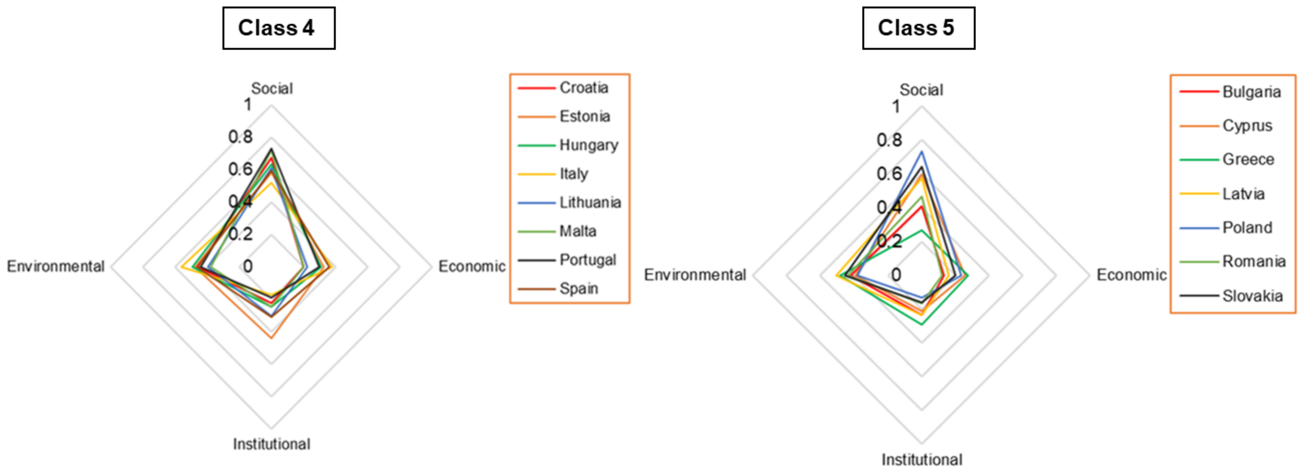


Figure 3: Dimension value distribution of class 4 and 5

Analyses show that a high global sustainability index (class 1) is mainly due to good performance in the economic, social and institutional dimensions since the environmental dimension has a lower level.
For countries in the lower classes, the results are mainly attributable to the low values in the economic and institutional dimensions; meanwhile the environmental sphere shows very similar values among the different classes.
Countries' performance in the social dimension ranges from medium to good level for the majority of them. As can be seen from Figure 4, the median value of the social sphere is high, indicating that more than half of the states achieve a value above 0.71. The highest value achieved in this dimension is that of Denmark (0.86), not too far from the median value. The worst states also perform well in this dimension with values greater than 0.4 with the exception of Greece, which has the lowest value (0.27).
For the economic and institutional dimensions, the median value is lower, 0.36 and 0.31 respectively. Moreover, the range of values is wider and shows great variability among the 27 states.
In the environmental sphere, the range of values is more contracted and in fact, as seen above, the values achieved by the different countries in the five classes have less variability and the median (0.45) is close to the average value.

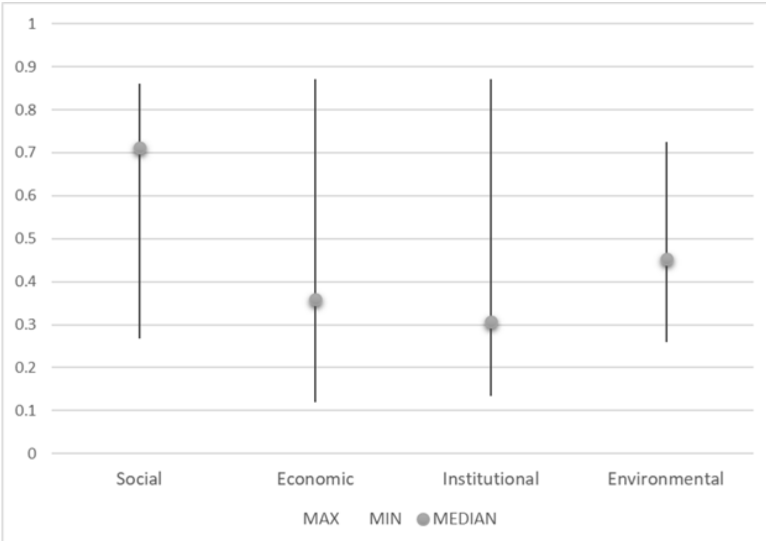


Figure 4: Range of values and median of dimension indexes

4. Discussion and conclusions

This study proposes an assessment of the social, economic, institutional, environmental and global level of the sustainable development reached from the 27 EU countries in the perspective of the 2030 Agenda. The evaluation is based on a set of 77 indicators extracted from the Eurostat SDG database and divided into the dimensions and sub-dimensions to which they pertain. Through the multi-criteria TOPSIS algorithm integrated in the geographic environment, three levels of aggregation were performed; the outputs are different sustainability indices (social, economic, environmental, institutional, and global) for each European state, that make possible to analyse which sub-dimensions and in particular which indicators lead to certain results.

Considering 2020 as the reference year, the results present a variegated situation, in which the Northern and Western European countries are generally the most advanced in terms of overall sustainability, showing good performance in all dimensions except the environmental one. On the contrary, the countries belonging to the ex-Soviet bloc along with the Mediterranean countries were more backward from them, showing important shortcomings especially in the economic and institutional dimensions.

The performance of the individual dimensions shows that environmental and social dimensions are generally the most 'resilient', showing stable values across countries, with few exceptions. However, countries with a higher level of global sustainability have, the worst values in environmental dimension.

The economic and institutional dimensions, on the other hand, show the opposite trend: they reach very high values for the most advanced countries in terms of global sustainability and decrease consistently to low levels for those countries with a weaker global index.

The results of this study are shown in an intuitive way through the representation of graphs and maps and they could be of great support for decision-makers in determining policies to be implemented in the direction of sustainable development.

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