An attempt to sustainable cities and society evaluation - MCDA based approach

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Abstract

The new paradigm for economic growth, social equality and environmental protection named sustainable development (SD) was introduced into the international community at the end of the 20th century. However, there are still difficulties in reliably assessing a specific objectives of SD. Among them the attention of many researchers has been drawn to sustainable city and society goal. In this study, we focus on data from 2013 to 2017 from EU countries in the context of their sustainable cities and society assessment. We propose a new approach to evaluating sustainable cities and society. A MCDA method called COMET was adopted to measure sustainability level. The obtained results were compared with reference MCDA methods called TOPSIS and VIKOR. The similarity coefficients are used to examine the similarity of final rankings. The motivation to choose the COMET method was a set of its abilities in opposite to the existing MCDA method, COMET is a rank reversal free method. Additionally, as a result of COMET model exploitation, the whole domain model is identified.

Keywords: MCDA, Sustainable development, Sustainable cites and society, Sustainability evaluation

1. Introduction

The new paradigm for economic growth, social equality and environmental protection named sustainable development was introduced into the international community at the end of the 20th century. In 1987, the World Commission on Environment and Development (Brundtland Commission) delineated sustainable development as a process leading to meet "*the needs of the* *present without compromising future generations ability to meet their own needs*" [19]. This definition clarifies primarily the essence of the concept, i.e. ability to self-sustain development that does not degrade the factors and mechanisms constituting it. The core of the sustainable development concept embraces two mutually exclusive ideas, the human needs to preserve natural resources and the needs to improve life quality. Initially, it combined two concerns about poverty and development with an environmental one [20]. Then, interpretations of this definition were advanced from 'pure ecologist', through "moderate ecologist", "crash barrier" and "3D" to "4D" [16]. The first two interpretations are purely focused on the ecological dimension. In the 'crash barrier' interpretation, the relationship with ecology is weaker, and it relates equally to social and ecological issues. "3D" defines other dimensions of sustainability, i.e. ecological, social and economic, that have equal importance and have to respect each other. In the "4D" approach, the cultural dimensions are introduced. Sustainable development is still a debatable concept, which is open to various interpretations, depending upon the given situation.

Generally, sustainable development involves transforming society and the economy, leading to various goals in terms of sustainability. Both terms, i.e., sustainability and sustainable development, are often used interchangeably [9], but it would be better to make a formal distinction between them [1]. Sustainability is a target goal of society and economic transformation. In contrast, sustainable development is a holistic transformation process that affects the achievement of sustainability in general and its various kinds [18]. The goals of sustainable development were identified by the 2030 Agenda for Sustainable Development and adopted by the world leaders in 2015 [8]. The agenda announced 17 Sustainable Development Goals (SDGs) and 169 targets that are integrated and indivisible and balance the three pillars of sustainable development, i.e., the economic, social, and environmental. The identified goals to be achieved by the year 2030, including the end of poverty (SDG 1), and hunger (SDG 2), good health and well-being for all (SDG 3), universal secondary education (SDG 4), access to affordable, sustainable and modern energy (SDG 7), sustainable cities and communities (SDG 11), actions to combat climate change (SDG 13), protecting and promoting sustainable use of the oceans, seas and marine (SDG 14) and of the terrestrial ecosystems (SDG 15), peaceful and inclusive societies (SDG 16) and the Global Partnership for Sustainable Development (SDG 17) [7]. All countries should work to implement the agenda at the regional and global levels and achieve specified goals, considering different national realities, capacities and levels of development and respecting national policies and priorities. Furthermore, to make rational decisions regarding activities and projects for achieving SDGs, countries need to have quantitative tools and measures for assessing these goals. There are 232 indicators identified by the agenda for measuring progress towards sustainable development and the goals achievements [7]. However, based on those 232 indicators, it is very difficult to assess and grasp the progress a country has made towards SDGs and highlight a few priority areas for urgent action [8]. Therefore, national statistical offices around the world, international agencies, think tanks, and researchers took on the challenge of looking for simple but comprehensive measures for assessing the level of SDGs achievement [3, 7].

The first attempt to elaborate a simple and comprehensive measure was the SDG index that was based on 34 indicators (two indicators per goal) and used to compare and rank all countries of the Organization for Economic Co-operation and Development (OECD) [3]. In 2016, this version of the SDG index was enhanced [12]. The new SDG index and dashboard report, including 77 indicators of which 14 variables are only available for OECD countries, were produced. In 2017, the SDG index and dashboard report methodology were refined, adjusting the index for spillover effect, which measures cross-border effects, to consider the international responsibilities of each country [13]. Various sets of indicators for measuring sustainability exist already, and it seems that constantly new ones are being developed. According to the 2030 Agenda for Sustainable Development [8], the multiple linkages to sustainability have been included and analyzed in E-Government Development Index (EGDI) in 2018. Selected or proxy themes related to e-government and sustainable development have been analyzed, for example, open government data, e-participation, mobile-government and whole-of-government approach. Van Kerk & Manuel created a comprehensive Sustainable Society Index [6]. It embraces 22 indicators grouped into five categories: personal development, clean environment, well-balanced society, sustainable use of resources, and sustainable world. Panda et al. developed a composite Urban Social Sustainability Index for assessing sustainable social development by Urban India [11]. It includes 27 indicators under seven themes, i.e. demography, education, health, equity, housing, poverty, and safety themes. The results of a comprehensive review of the sustainability measurement literature are made by Mura et al. [7].

When analyzing the literature, an interesting methodological research gap should be pointed out. It concerns the very limited use of multi-criteria decision support methods in the sustainability measurement process. It should be noted that multi-criteria methods, apart from the natural possibility of data aggregation and ranking of alternatives, have a great potential for modelling both strategies and operational goals. The multi-criteria methods are also a very useful tool for benchmarking.

In this paper, a new approach to sustainable cites and society evaluation is proposed. MCDA method called COMET was used to measure the sustainability of cities and communities in European countries. As the COMET method is relatively new, results obtained were compared with reference MCDA methods called TOPSIS and VIKOR. The Pearson correlation coefficient was used to examine the similarity of final rankings. The motivation behind the COMET method selection was a set of its abilities – in opposite to the existing MCDA methods, COMET is a rank reversal free method. Additionally, as a result of COMET model exploitation, the full domain model is identified.

The rest of the paper is organized as follows. Section 2 presents the MCDA methods preliminary. In section 3, a study case containing an evaluation of cities and communities' sustainability in EU countries was made. Finally, in Section 4, conclusions from the research and further directions are given.

2. Preliminaries

2.1. TOPSIS technique

This approach has obtained popularity thanks to the simplicity of calculations. The decision-maker determines the weighting of the decision criteria, and all subsequent calculations are carried out without an expert's participation. A detailed study of the TOPSIS algorithm based on [2] is presented as follow. We assume that the decision matrix has m alternatives, and n criteria are represented as $X = (x_{ij})_{m \times n}$.

Step 1. Calculate the normalized decision matrix. The normalized values r_{ij} calculated according to normalization equation for profit cost criteria.

Step 2. Calculate the weighted normalized decision matrix v_{ij} according to equation (1).

$$v_{ij} = w_i r_{ij} \tag{1}$$

Step 3. Calculate Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) vectors. PIS is defined as maximum values for each criteria (2) and NIS as minimum values (3). We don't need to split criteria into profit and cost here, because in step 1 we use normalization which turns cost criteria into profit criteria.

$$v_j^+ = \{v_1^+, v_2^+, \cdots, v_n^+\} = \{max_j(v_{ij})\} \tag{2}$$

$$v_j^- = \{v_1^-, v_2^-, \cdots, v_n^-\} = \{min_j(v_{ij})\} \tag{3}$$

Step 4. Calculate distance from PIS and NIS for each alternative. As shows equations (4) and (5).

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \tag{4}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \tag{5}$$

Step 5. Calculate each alternative's score according to equation (6). This value is always between 0 and 1, and the alternatives which got values closer to 1 are better.

$$C_i = \frac{D_i^-}{D_i^- + D_i^+} \tag{6}$$

2.2. VIKOR

VIKOR is an acronym in Serbian that stands for VlseKriterijumska Optimizacija I Kompromisno Resenje. The decision maker chooses an alternative that is the closest to the ideal and the solutions are assessed according to all considered criteria. The VIKOR method was introduced by Opricovic [10]. These both methods are based on closeness to the ideal objects [15]. However, they differ in their operational approach and how these methods consider the concept of proximity to the ideal solutions.

The VIKOR method, similarly to the TOPSIS method, is based on distance measurements. The description of the method will be quoted according to [15].

Step 1. Determine the best f_i^* and the worth f_i^- values for each criteria functions. Use (7) for profit criteria and (8) for cost criteria.

$$f_j^* = \max_i f_{ij}, \quad f_j^- = \min_i f_{ij} \tag{7}$$

$$f_j^* = \min_i f_{ij}, \quad f_j^- = \max_i f_{ij} \tag{8}$$

Step 2. Calculate the S_i and R_i values by Equations (9) and (10).

$$S_i = \sum_{j=1}^{n} w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right) \tag{9}$$

$$R_i = \max_j \left[w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right)\right] \tag{10}$$

Step 3. Compute the Q_i values using Equation (11).

$$Q_i = v\left(S_i - S^*\right) / \left(S^- - S^*\right) + (1 - v)\left(R_i - R^*\right) / \left(R^- - R^*\right) \tag{11}$$

where
$S^* = \min_i S_i, \quad S^* = \min_i S_i$
$R^* = \min_i R_i, \quad R^* = \max_i R_i$
and v is introduced as a weigh for the strategy "majority of criteria". We use $v = 0.5$ here.
Step 4. Rank alternatives, sorting by the values S, R, and Q in ascending order. Result is three ranking lists.
Step 5. We use S, R, and Q ranking lists to propose the compromise solution or set of compromise solutions, as shown in [10]. However, in this paper would use only the Q ranking list.

2.3. COMET

The COMET is a newly developed method for identifying a multi-criteria expert decision-making model to solve decision-making problems. This method will be presented in five steps based on [14]:

Step 1. An expert define dimensionality of the problem by selecting number r of criteria, $C_1, C_2, ..., C_r$. Subsequently, the set of fuzzy numbers for each criterion C_i is selected, i.e., $\tilde{C}_{i1}, \tilde{C}_{i2}, ..., \tilde{C}_{ic_i}$. Each fuzzy number determines the value of the membership for a particular linguistic concept for specific crisp values. Therefore it is also useful for variables that are not continuous. In this way, the following result is obtained (12).

$$\begin{array}{l} C_1 = \{\tilde{C}_{11}, \tilde{C}_{12}, ..., \tilde{C}_{1c_1}\} \\ C_2 = \{\tilde{C}_{21}, \tilde{C}_{22}, ..., \tilde{C}_{2c_1}\} \\ .... \\ C_r = \{\tilde{C}_{r1}, \tilde{C}_{r2}, ..., \tilde{C}_{rc_r}\} \end{array} \tag{12}$$

where $c_1, c_2, ..., c_r$ are numbers of the fuzzy numbers for all criteria.

Step 2. Characteristic objects are generated objects that define reference points in n-dimensional space. They can be either real or idealized objects that cannot exist. The characteristic objects (CO) are obtained by using the Cartesian product of fuzzy numbers cores for each criteria. As the result, the ordered set of all CO is obtained (13):

$$\begin{array}{l} CO_1 = \{C(\tilde{C}_{11}), C(\tilde{C}_{21}), ..., C(\tilde{C}_{r1})\} \\ CO_2 = \{C(\tilde{C}_{11}), C(\tilde{C}_{21}), ..., C(\tilde{C}_{r2})\} \\ .... \\ CO_t = \{C(\tilde{C}_{1c_1}), C(\tilde{C}_{2c_2}), ..., C(\tilde{C}_{rc_r})\} \end{array} \tag{13}$$

where t is a number of CO (14):

$$t = \prod_{i=1}^{r} c_i \tag{14}$$

Step 3. The expert determines the Matrix of Expert Judgement (MEJ). It is a result of pairwise comparison of the characteristic objects by the expert knowledge. The MEJ structure is as follows (15):

$$MEJ = \begin{pmatrix} \alpha_{11} & \alpha_{12} & ... & \alpha_{1t} \\ \alpha_{21} & \alpha_{22} & ... & \alpha_{2t} \\ ... & ... & ... & ... \\ \alpha_{t1} & \alpha_{t2} & ... & \alpha_{tt} \end{pmatrix} \tag{15}$$

where α_{ij} is a result of comparing CO_i and CO_j by the expert. The more preferred characteristic object gets one point and the second object get zero points. If the preferences are balanced, the both objects get half point. It depends solely on the knowledge of the expert and can be presented as (16):

$$\alpha_{ij} = \begin{cases} 0.0, & f_{exp}(CO_i) < f_{exp}(CO_j) \\ 0.5, & f_{exp}(CO_i) = f_{exp}(CO_j) \\ 1.0, & f_{exp}(CO_i) > f_{exp}(CO_j) \end{cases} \tag{16}$$

where f_{exp} is an expert mental judgement function. Afterwards, the vertical vector of the Summed Judgements (SJ) is obtained as follows (17):

$$SJ_i = \sum_{j=1}^{t} \alpha_{ij} \tag{17}$$

The number of query is equal $p = \frac{t(t-1)}{2}$ because for each element α_{ij} we can observe that $\alpha_{ji} = 1 - \alpha_{ij}$. In the result, the vector P is obtained, where i-th row contains the approximate value of preference for CO_i.

Step 4. Each characteristic object is converted into a fuzzy rule, where the degree of belonging to particular criteria is a premise for activating conclusions in the form of P_i. Each characteristic object and value of preference is converted to a fuzzy rule as follows detailed form (18). In this way, the complete fuzzy rule base is obtained, that approximates the expert mental judgement function $f_{exp}(CO_i)$.

$$IF \quad C_1 \,\tilde{}\, \tilde{C}_{1i} \quad AND \quad C_2 \,\tilde{}\, \tilde{C}_{2i} \quad AND \quad ... \quad THEN \quad P_i \tag{18}$$

Step 5. The each one alternative A_i is a set of crisp numbers a_{ri} corresponding to criteria $C_1, C_2, ..., C_r$. It can be presented as follows (19):

$$A_i = \{a_{1i}, a_{2i}, ..., a_{ri}\} \tag{19}$$

3. Empirical study towards sustainable cities and society evaluation - EU countries perspective

In this paper, we have selected a group of MCDA methods to evaluate the sustainable cities and society level of EU countries. Using reference criteria provided in [17] and [4] and data set provided in EUROSTAT database [4, 5] MCDA based models have been developed for all EU countries. To provide a multi-criteria assessment, and according to [17] and [4] the ten criteria were taken into consideration, namely overcrowding rate, households living population with given disruptions, settlement area per capita, road death accidents, air pollution, recycling rate, house damages, access to secondary waste of water treatment, passenger transport and crime and violence occurrence. They were selected based on their relevance to the sustainability of country performance. The detailed description of the criteria set is presented in Table 1.

Table 1. The sustainability in cities and society evaluation criteria.

C_i	Criterion	Unit	Preference Direction
C1	Overcrowding rate by poverty status	% of population	Min
C2	Population living in households considering that they suffer from noise, by poverty status	% of population	Min
C3	Settlement area per capita	m2 per capita	Max
C4	People killed in road accidents	number	Min
C5	Exposure to air pollution by particulate matter	μg/m3	Min
C6	Recycling rate of municipal waste	% of total waste generated	Max
C7	Population living in a dwelling with a leaking roof, damp walls, floors or foundation or rot in window frames of floor by poverty status	% of population	Min
C8	Population connected to at least secondary waste water treatment	% of population	Max
C9	Share of busses and trains in total passenger transport	% of total inland passenger-km	Max
C10	Population reporting occurrence of crime, violence or vandalism in their area by poverty status	% of population	Min

The countries taken into consideration were Belgium, Bulgaria, Czechia, Denmark, Germany, Estonia, Greece, France, Croatia, Latvia, Luxemburg, Hungary, Netherlands, Poland, Romania, Slovenia, Finland, Sweden and Norway, which, overall give 19 alternatives to compare. As it was pointed, Data for each criterion for a given country was taken from the EUROSTAT database [4, 5]. In the next step, a decision matrix containing performance values for

Table 2. Decision matrix for analyzed countries for data collected in 2015.

Country	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Belgium	1.6	18	581.6	762	13.5	53.5	18.2	80.46	18.8	16.1
Bulgaria	41.4	9.7	613.5	708	25	29.4	12.9	60.7	16.9	26.3
Czechia	18.7	13.9	616.1	734	17.4	29.7	8.9	80.7	25.9	12
Denmark	8.1	16.5	1052.3	178	11.3	47.4	16.1	90.8	19.1	7.7
Germany	7	25.8	564.8	3459	13.3	66.7	12.8	95.766	14.4	13.8
Estonia	13.4	9.4	1540.5	67	6.7	28.3	13.4	87.61	21.8	11.8
Greece	28.1	19.2	627.7	793	16.4	15.8	15.1	93.4	18.6	12.8
France	7.4	16.4	835.2	3459	13.5	40.7	12.6	80	17.2	14.2
Croatia	41.7	8.3	670.7	348	20.8	18	10.9	36.9	14.1	2.8
Italy	27.8	18.3	471.5	3428	21.6	44.3	24.1	59.6	18.6	19.4
Latvia	41.4	14.6	1297.2	188	15.9	28.7	24.4	90.29	19.3	11.8
Luxembourg	6.8	20.1	511.7	36	11.7	47.4	14.4	96.6	17.1	14.9
Netherlands	3.3	24.7	471.6	531	12.7	51.8	15.7	99.43	13.9	17.4
Poland	43.4	12.4	623.9	2938	23.8	32.5	11.9	72.6	21.5	5.8
Romania	49.7	22.2	364.8	1893	17.1	13.2	12.8	39.7	20.1	13.1
Slovenia	13.7	12.9	609.2	120	21.6	54.1	26.9	57.4	13.9	9.2
Sweden	13.9	12.6	2343.8	259	5.8	47.5	7.7	95	16.8	10.9

every alternative was constructed.

Table 3. Preference values and rankings for analyzed alternatives for data collected in 2015.

Country	Preference			Rankings		
	TOPSIS	VIKOR	COMET	TOPSIS	VIKOR	COMET
Belgium	0.547	0.689	0.576	5	7	5
Bulgaria	0.390	0.386	0.409	15	14	15
Czechia	0.536	0.508	0.561	6	11	6
Denmark	0.655	0.608	0.657	3	9	3
Germany	0.455	0.394	0.485	12	13	11
Estonia	0.689	0.781	0.671	2	2	2
Greece	0.459	0.519	0.480	11	10	12
France	0.454	0.246	0.478	13	16	13
Croatia	0.495	1.000	0.500	10	1	10
Italy	0.276	0.277	0.324	17	15	17
Latvia	0.513	0.429	0.510	9	12	9
Luxembourg	0.565	0.742	0.595	4	5	4
Netherlands	0.528	0.683	0.556	8	8	7
Poland	0.391	0.139	0.418	14	17	14
Romania	0.320	0.698	0.344	16	6	16
Slovenia	0.529	0.748	0.538	7	4	8
Sweden	0.789	0.767	0.750	1	3	1

However, the lack of data for specific years for criterion C_3 cause the fact that it was not considered with a significant amount of examined sets. The conducted research was based on the analysis of decision matrices containing data collected for individual countries in 2013-2017. Table 2 presents the exemplary decision matrix with the criteria for the considered countries registered in 2015. Table 3 shows the preference values and positional rankings for analyzed alternatives for data collected in 2015. The final results were obtained using TOPSIS, VIKOR and COMET methods. The same calculations were performed for 2013, 2014, and 2016 and 2017 datasets.

To provide a comprehensive analysis and compare the preference values obtained by the selected MCDA methods, the TOPSIS method results for the years 2013-2017 were calculated. They are presented in Table 4. In this case, it was decided to cluster countries with sufficient data to assess them at least once. Consequently, in the selected years, some countries were not subjected to MCDA methods and did not obtain preference values from the multi-criteria model.

Table 4. Comparison of the TOPSIS method countries preferences for data collected in 2013-2017.

Country	2013	2014	2015	2016	2017
Austria	NaN	0.705	NaN	0.714	NaN
Belgium	0.617	0.652	0.547	0.663	0.682
Bulgaria	0.442	0.430	0.390	0.459	0.481
Croatia	0.532	0.557	0.495	0.576	0.618
Czechia	0.601	0.630	0.536	0.659	0.708
Denmark	0.726	0.729	0.655	0.733	0.753
Estonia	0.627	0.685	0.689	0.730	0.767
Finland	0.725	0.740	NaN	NaN	NaN
France	0.456	0.478	0.454	0.435	0.422
Germany	0.485	0.494	0.455	0.474	NaN
Greece	0.509	NaN	0.459	0.545	NaN
Hungary	0.513	0.501	NaN	NaN	0.582
Ireland	NaN	0.721	NaN	0.748	0.764
Italy	NaN	NaN	0.276	NaN	NaN
Latvia	0.531	0.509	0.513	0.552	0.599
Luxembourg	0.682	0.672	0.565	0.676	0.697
Netherlands	0.623	0.619	0.528	0.624	0.644
Norway	0.721	0.745	NaN	0.767	0.776
Poland	0.376	0.408	0.391	0.417	0.423
Portugal	NaN	NaN	NaN	NaN	0.602
Romania	0.344	0.387	0.320	0.362	0.398
Slovakia	NaN	NaN	NaN	0.630	0.669
Slovenia	0.578	0.578	0.529	0.628	0.669
Spain	NaN	0.593	NaN	NaN	NaN
Sweden	0.755	0.748	0.789	0.730	0.730
United Kingdom	NaN	0.555	NaN	NaN	NaN

In contrast, Table 5 contains the preference values obtained with the use of VIKOR method for the years 2013-2017 for the selected countries. On the other hand, Table 6 shows the preference values obtained using the COMET method for the period 2013-2017. However, this time only the countries that were ranked in each of the periods considered are included. When analyzing the aggregated preference values contained in Table 4, Table 5, and Table 6 it is worth pointing that the results obtained with the use both the COMET method and TOPSIS and VIKOR methods show a very high convergence of rankings.

Table 5. Comparison of the VIKOR method countries preferences for data collected in 2013-2017

Country	2013	2014	2015	2016	2017
Austria	NaN	0.303	NaN	0.181	NaN
Belgium	0.597	0.628	0.689	0.614	0.485
Bulgaria	0.448	0.162	0.386	0.136	0.299
Croatia	0.896	0.894	1.000	0.844	0.853
Czechia	0.222	0.221	0.508	0.203	0.324
Denmark	0.626	0.595	0.608	0.490	0.548
Estonia	0.800	0.778	0.781	0.812	0.852
Finland	0.935	0.917	NaN	NaN	NaN
France	0.317	0.317	0.246	0.231	0.274
Germany	0.200	0.187	0.394	0.178	NaN
Greece	0.479	NaN	0.519	0.362	NaN
Hungary	0.111	0.014	NaN	NaN	0.000
Ireland	NaN	0.877	NaN	0.890	0.887
Italy	NaN	NaN	0.277	NaN	NaN
Latvia	0.482	0.401	0.429	0.447	0.514
Luxembourg	0.662	0.663	0.742	0.597	0.583
Netherlands	0.568	0.499	0.683	0.532	0.476
Norway	1.000	1.000	NaN	1.000	1.000
Poland	0.484	0.109	0.139	0.112	0.181
Portugal	NaN	NaN	NaN	NaN	0.496
Romania	0.571	0.617	0.698	0.572	0.591
Slovakia	NaN	NaN	NaN	0.678	0.551
Slovenia	0.691	0.687	0.748	0.542	0.582
Spain	NaN	0.502	NaN	NaN	NaN
Sweden	0.827	0.790	0.767	0.708	0.726
United Kingdom	NaN	0.322	NaN	NaN	NaN

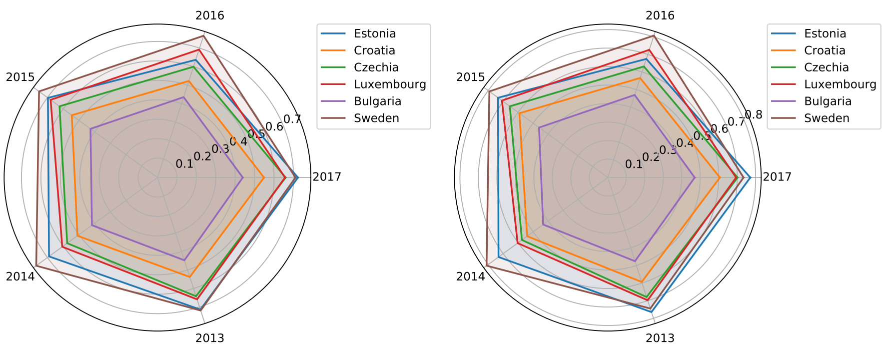

Fig. 1. Preferences comparison of countries obtained with the COMET (leeft) and TOPSIS (right) methods.

Additionally, a data visualization for the preference values of the countries that were ranked in each year is shown in Figure 1 for the COMET, and TOPSIS methods, respectively. It is worth noting that the analysis of alternatives, taking into account the indicated criteria, showed that Sweden and Croatia were definitely in the lead among the considered EU countries. On the other hand, the countries rated the worst using the selected MCDA methods were Bulgaria, Poland and Romania. Considering the given preference values, the listed countries at the end of the ranking received a score twice as low as the best-ranked options. It indicates a significant differentiation in the level of achievement of sustainable cities and society goals.

Table 6. Comparison of the COMET method countries preferences for data collected in 2013-2017

Country	2013	2014	2015	2016	2017
Austria	NaN	0.678	NaN	0.680	NaN
Belgium	0.599	0.635	0.576	0.637	0.652
Bulgaria	0.422	0.417	0.409	0.440	0.439
Croatia	0.506	0.529	0.500	0.528	0.544
Czechia	0.580	0.605	0.561	0.628	0.658
Denmark	0.687	0.693	0.657	0.683	0.697
Estonia	0.608	0.663	0.671	0.692	0.712
Finland	0.701	0.707	NaN	NaN	NaN
France	0.488	0.502	0.478	0.478	0.501
Germany	0.513	0.518	0.485	0.514	NaN
Greece	0.503	NaN	0.480	0.516	NaN
Hungary	0.495	0.492	NaN	NaN	0.525
Ireland	NaN	0.690	NaN	0.706	0.717
Italy	NaN	NaN	0.324	NaN	NaN
Latvia	0.507	0.493	0.510	0.513	0.529
Luxembourg	0.655	0.649	0.595	0.635	0.647
Netherlands	0.604	0.601	0.556	0.598	0.618
Norway	0.690	0.711	NaN	0.719	0.725
Poland	0.399	0.428	0.418	0.441	0.450
Portugal	NaN	NaN	NaN	NaN	0.546
Romania	0.351	0.389	0.344	0.367	0.389
Slovakia	NaN	NaN	NaN	0.591	0.602
Slovenia	0.544	0.548	0.538	0.576	0.606
Spain	NaN	0.591	NaN	NaN	NaN
Sweden	0.721	0.717	0.750	0.698	0.696
United Kingdom	NaN	0.562	NaN	NaN	NaN

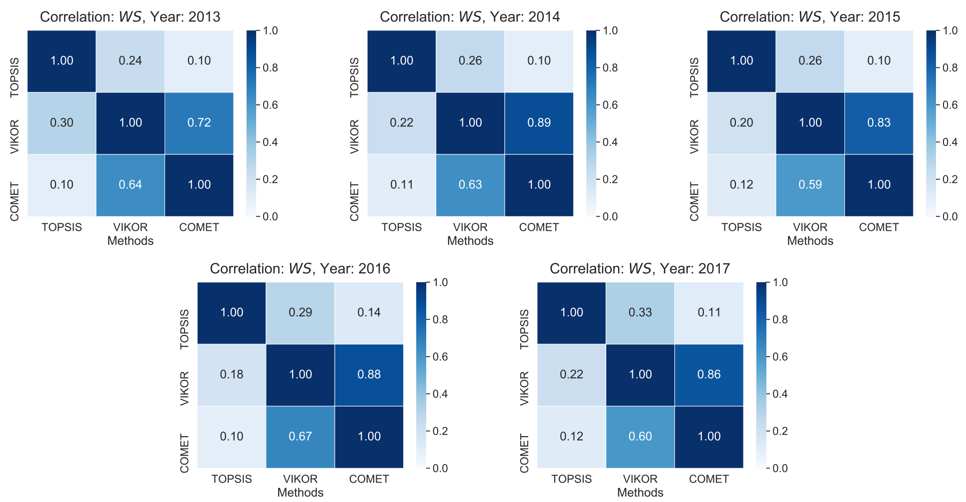

Fig. 2. The correlation values between the final rankings in the considered years.

Consistent with the aim of this study, it was decided to formally compare the results obtained by TOPSIS, VIKOR and COMET for consecutive years within each of these methods. For this purpose, the Pearson correlation coefficient was used, and it was applied to measure the similarity of the results obtained for each of the criteria used in the study. Due to the impossibility of examining alternatives when considering the C3 criterion for the periods analyzed, it was decided to omit this criterion from the correlation study of the values obtained. Figure 2 presents the correlation values between the final rankings for the analyzed years for the COMET, VIKOR and TOPSIS methods respectively. These values clearly show very high correlation of the rankings obtained using both COMET and TOPSIS and COMET and VIKOR methods.

4. Conclusions

The sustainability evaluation is an essential aspect of both theory and practice. This study aimed to construct a multi-criteria model supporting sustainable cities and society evaluation for EU countries. For this purpose, the COMET method based model was constructed. Results were compared with reference MCDA methods based models called TOPSIS and VIKOR. The results showed that the methods used gave similar results for preference values and positional rankings over the analyzed period.

The study shows that the developed model has high utility and wide practical aspects. Analyzing the study's methodological perspective, it should be emphasized that even the reference methods TOPSIS and VIKOR showed their potential in the area of sustainable cities and society evaluation. When analyzing the COMET method's properties, the very high compatibility of the results obtained with this method concerning the reference methods should be pointed. Additionally, the COMET method features such as the lack of necessity to define subjective weights of attributes, and full domain coverage of the developed model indicate this method's superiority. The above arguments unambiguously confirm the usefulness of using the COMET method as an algorithmic basis for the developed sustainable cities and societies measurement model.

During the research, directions for further work and improvements to the resulting model were identified. It seems to be a natural practical direction of research to undertake studies in building models for evaluating other sustainable development goals using MCDA methods. In the methodical dimension, the implementation of algorithms of MCDA methods based on fuzzy numbers arithmetic seems to be a very promising research field.

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