Towards MCDA based decision support system addressing sustainable assessment

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Abstract

Nowadays, the efforts to achieve sustainable development in many areas are a challenge creating the necessity to introduce innovations in management. Objective assessment of realization of set goals requires taking into account many often conflicting criteria. This work aims to present an attempt to implement a decision support system (DSS) based on multi-criteria decision analysis methods for autonomous sustainable evaluation in any problem area. The system's capabilities are illustrated in the example of using renewable energy sources in European countries. This problem is one of the current challenges related to climate change and exhaustion of natural energy resources, which forces changes in energy policy, taking into account, among others, the increase in the share of renewable energy sources in many branches of the economy. The obtained results prove that the system proposed by the authors is an appropriate and valuable tool for assessing sustainability in problems involving various areas.

Keywords: sustainable assessment, decision support system, DSS, multi-criteria decision analysis, sustainability in renewable energy sources problems.

1. Introduction

Decision support systems (DSS) are interactive computer systems that help decision-makers use data and components to solve problems [28]. The main goal of a DSS is to help people perform more effective decision making [2]. DSSs were developed in the 1960s and 1970s to support business managers. In these decades, the rapid evolution of information systems was observed. Later, they aroused attention to environmental quality management and are considered fundamental to the sustainable management of the land and marine ecosystems. During this time, there was an intensive adaptation of DSS to take into account the different dimensions of the problem to be solved (environmental, social and economic) [1]. Decision support systems are component-based using artificial neural network (ANN) models, machine learning (ML), reinforcement learning (RL), rules and multi-criteria decision analysis methods (MCDA) [3], [13]. DSS refers to technology and application that assists DMs in using data through models to solve semi-structured and unstructured problems [17]. In recent years, the nature of DSS tools has evolved significantly, and they are now equipped with a variety of tools such as graphics, interactive visual modelling, artificial intelligence techniques, fuzzy sets and genetic algorithms [9].

DSSs are mainly organized into three large modules that complete the activities. The first module collects data related to the issue under study. This information can be qualitative or quantitative. All these data are organized in a central module of the structure, which contains an algorithmic, methodical based engine for processing and evaluating them with multiple criteria. The evaluation results go to a third module where they can be presented using various visual techniques. The results obtained can then be disseminated in the form of technical reports [16].

Multi-criteria decision making is one of the most effective ways of solving problems to choose the right decision among many choices. Effectiveness and potential of MCDAs cause that it is used in various fields such as computer science and information technology, agriculture, economy, management and business. Decision making is complex in situations based on multiple criteria. Despite the great analytical possibilities, the use of MCDA methods in DSS systems is very limited. Most often, they are only tools for the system analyst impossible to use directly in a given class of real problems (see `http://www.cs.put.poznan.pl/ewgmcda/index.php/software`). Hence, this paper attempts to build MCDA methods based DSS supporting sustainable assessment. Using the proposed methodical background of DSS, the sample problem of evaluating the share of renewable energy sources in the economy of European countries is solved.

The rest of the paper is organized as follows: Section 2 provides a literature review of MCDA methods and their application to systems and tools for evaluating the problem exemplified by the authors' study, i.e., evaluating the management of renewable energy sources. Section 3 presents the foundations of the decision support system that is the subject of this paper, along with the fundamentals and assumptions of MCDA methods. Section 4 introduces the results of the study, which are discussed in Section 5. Finally, we present the conclusions in Section 6 and future directions in Section 7.

2. Literature review

Decision support systems are tools designed for situations where there is uncertainty, incomplete information and where risk-related decisions must be made using human judgments and preferences. The purpose of DSSs is to bridge the gap between decision-making and analytical tools and human interaction. DSSs can perform many tasks, such as enabling the flow of information and knowledge and helping decision-makers better understand the problem being solved and clarify judgments and preferences [28].

The multi-criteria analysis involves various methodologies that offer aggregation and evaluation of multiple, often conflicting and incommensurate alternatives. One of the strengths of this approach is that it can incorporate both qualitative and quantitative criteria. Their advantage over traditional economic analysis lies in their ability to model the priorities of decision-makers and stakeholders [2].

Analysis of issues with multiple decision criteria, often conflicting with each other, requires the involvement of experts in the domain of the problem under consideration [5]. One of the more complex in terms of the planning and evaluation process is evaluating energy policy and renewable energy management. Multi-criteria methods are tools that have great potential for evaluation and ranking, in which many different criteria are taken into consideration in a systematic way [8]. The criteria assessed in renewable energy research are divided into four main categories: financial, technical, environmental, and social. Besides, political criteria are also taken into account [24]. The presence of multiple criteria requires that trade-offs between them be considered before a comprehensive assessment can be made, which can be achieved using Multiple Criteria Decision Analysis (MCDA) methods, assist the decision-maker in identifying the best alternative [5].

Assessment of energy policy and sustainable management of renewable energy sources can be performed by analyzing renewable energy production and consumption dynamics in different sectors of the economy. Because this problem takes into account many different criteria, as well as a result of literature studies, it can be assumed that the methods appropriate for its solution are MCDA. They make it possible to create objective and representative rankings of countries regarding their overall use of renewable energy [25]. It is recommended to compare the results obtained using different MCDA methods, which will make it possible to determine the stability of the obtained rankings, the occurring correlations between them using correlation and similarity coefficients, and the usefulness of the used methods in the considered problem [14].

Various criteria are considered in evaluating sustainable management planning for renewable energy sources. They may relate to land, investment costs, social and political acceptance [19]. The Renewable Energy Sustainability Assessment evaluates the use of individual sources of renewable energy, i.e. hydro, solar, wind, geothermal, biomass energy, in terms of gross annual production volume and energy efficiency [12]. Examples of methods used are TOPSIS, VIKOR and their fuzzy versions COPRAS, PROMETHEE, ELECTRE, AHP [4], [26]. An important criterion is also the amount of consumption (use) of renewable energy according to its type. The TOPSIS method is commonly used for this purpose because of its ease of application or its fuzzy version [23]. The TOPSIS method is suitable for the evaluation of renewable energy storage systems and zero-emission heating systems [27].

The above analysis of the literature clearly shows the great potential of MCDA methods in the energy market domain and sustainability more widely. On the one hand, it gives a strong justification for the use of MCDA methods in this class of problems, and on the other hand, it indicates the need for in-depth analysis of individual problems. In this aspect, this paper answers the question about the desirability of using MCDA methods as a methodical foundation of RES assessment DSS.

3. The Engine of Decision Support System

This paper aims to present a decision support system whose main component is designed to support independent and objectified decision analysis in a multi-criteria environment. This system is completely automated and does not require the involvement of the analyst and decision-maker in the analysis and evaluation process. A flow chart of the system described is displayed in Figure 1.

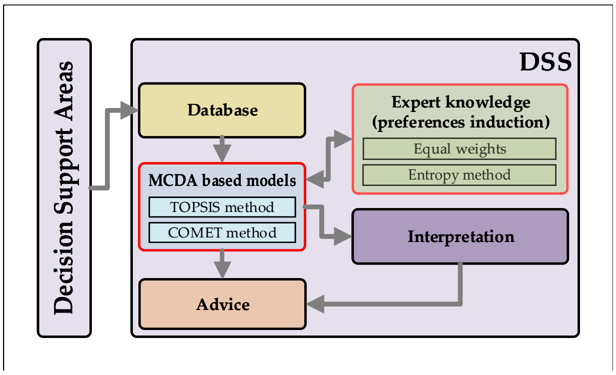


Fig. 1. The flow chart of the DSS with component based on MCDA methods

In the proposed DSS, the sustainable assessment is realized not only by algorithms of TOPSIS and COMET methods but, first of all, by objective techniques of criteria weighting, i.e. equal weights and entropy weights. In addition, the use of the entropy weights technique allows for a balanced and objective (feature-based) evaluation of alternatives. They not only objectify the assessment model but additionally allow to treat all its features as equivalent (equal weights). In addition, the use of the entropy weight technique allows for a balanced and objective (dependent on the value of individual features) evaluation of alternatives. The problem of choosing the appropriate multi-criteria method to evaluate alternatives in a particular problem is complex. The choice of a method is preceded by the definition of criteria considered in the evaluation of alternatives. In order to objectively evaluate the problem that takes place in the main component of the system, the authors used MCDA methods, the practical application of which in the problem of RES evaluation has been confirmed in the literature, and objective methods for determining the criteria weights. In this problem, an important role is played by benchmarking, i.e. comparing the results obtained by different methods. The benchmark, with which the results of the tested methods are compared, can represent a ranking established by experts, the results obtained using another method, or a study of the compatibility of the rankings obtained using individual MCDA methods [21].

By analyzing the available MCDA methods and applying the literature guidelines for selecting MCDA methods for a decision problem contained in the works [29] and website system supporting MCDA methods selection process located in `www.mcda.it`. The author's approach decided to use two complementary MCDA methods TOPSIS (Technique of Order Preference Similarity) and COMET (The Characteristic Objects METhod). Substantively it was dictated by the fact that these methods are based on the idea of "reference points" enabling decision-makers not only to build objectified rankings taking into account all criteria of the decision problem but also to build "ideal points" which are a set of maximum values of particular criteria to obtain in the given problem. From a methodological point of view, these methods show great potential for modelling the structure of the problem and decision-makers' preferences and are adapted to deterministic data, and such are available for the given problem. Additionally, the possibility of modelling the weights in the TOPSIS method creates good conditions for mapping the conditions of individual countries in the model (e.g. reduced relevance of photovoltaic RES in Norway). For objectification of results and comparative modelling, the COMET method was also used. In this case, the idea of characteristic objects makes it unnecessary to use relative criterion weights, and the formal assumptions of this method mean that the effect of linear compensation of criteria is limited here.

The rank reversal paradox is a significant challenge for MCDA methods. This phenomenon involves a change in the ranking of alternatives when an alternative is added or removed, which is inconsistent with the principle of independence of irrelevant alternatives. The most important methods in recent years resistant to the rank reversal phenomenon include Ranking of Alternatives through Functional mapping of criterion sub-intervals into a Single Interval (RAFSI) [31], Stable Preference Ordering Towards Ideal Solution (SPOTIS) [6] and the Characteristic Objects Method (COMET) [20]. Apart from resistance to the rank reversal phenomenon, the COMET method's main advantages are high accuracy and not requiring arbitrary weights [11].

All stages of the work, including data preparation, implementation of MCDA methods which are the core of the autonomic evaluation system, and analysis of results, were performed in Python programming language, in Visual Studio Community programming environment. The choice of this programming language is justified because Python provides many solutions helpful in data analysis and work on large data sets. Numerous open-source libraries allow building algorithms quickly and efficiently. Python also provides excellent opportunities for visualization and statistical analysis of data sets. Microsoft Visual Studio Community 2019 is a popular and intuitive-to-use development environment that uses multiple programming languages, including Python. It has a user-friendly interface able to modify and extend existing projects easily and import the necessary libraries. A Python implementation of the MCDA methods underlying the system presented in this work is provided in the GitHub repository available at `https://github.com/UserXXXXX/ISD-2021-MCDA-RES-EU`.

3.1. The TOPSIS Method

TOPSIS (Technique of Order Preference Similarity) method is a popular MCDA method proposed by Hwang and Yoon in 1980 [23]. It involves finding the best alternative that is as close as possible to the ideal solution and as far as possible from the anti-ideal solution. It is performed by comparing the decision options under consideration with abstract weighted reference solutions: ideal and anti-ideal. This approach measures the distances of the alternatives from the reference elements, which are the positive and negative ideal solution, respectively [21]. Due to its simplicity, this method is widely used in solving multi-criteria problems. The ranking of alternatives is obtained by comparing Euclidean distances. The TOPSIS method requires weights for each criterion that aggregate to a value of 1 [22].

3.2. The COMET Method

The COMET method for solving multi-criteria decision problems is based on fuzzy logic, triangular fuzzy sets, and the idea of characteristic objects, i.e., points distributed in the state space of the problem under consideration. The objects are determined as a combination of the characteristic values for each criterion. It is a method that does not have many disadvantages identified in the multi-criteria decision analysis methods. It is resistant to the rank reversal phenomenon, i.e. the reversal of rankings when a new alternative is added or when an alternative is removed from the set of considered objects. Once identified, the model constantly returns the same values of scores for all evaluated objects [20]. The pairwise comparison used in the COMET method makes it resistant to human mistakes. The expert decides here only on the superiority of one characteristic object over another, not on the strength of this superiority. An interesting property of the COMET method is that there is no need to use weights to determine the criteria's importance. Their relevance is determined directly during the determination of the MEJ matrix. Therefore, this method can reflect the preferences of the decision-maker more realistically. In this method, if there are many criteria, it is advisable to create a hierarchical structure of models by decomposing the complex decision model. As a result of the decomposition, the resulting structure consists of modules, where each module has a reduced number of input variables. The outputs of subsequent models are new inputs to subsequent modules. Determining the appropriate structure by an expert is a challenge. The general rule for determining hierarchy indicates that related criteria should be grouped. By decomposing and hierarchizing the problem, it is possible to reduce the number of pairwise comparisons required significantly [10].

4. Sample presentation of DSS engine capabilities in EU RES evaluation

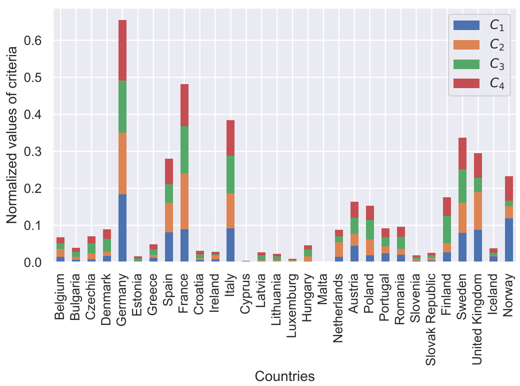


Fig. 2. Aggregated, normalized values of selected criteria for studied countries in 2018, source: EUROSTAT

- C_1–Annual electricity production from all renewable energy sources in GW hour/year
- C_2–Annual energy consumption from all renewable sources in transport in thousand tonnes of oil equivalent (KTOE)
- C_3–Annual energy consumption from all renewable sources in heating and cooling and for heat pumps in KTOE
- C_4–Gross final consumption of energy from renewable sources for all purposes in KTOE

The study considers an illustrative exemplary dataset of the 30 countries of the European Economic Area listed in Figure 2 for the period 2014–2018. The selection of the criteria considered in the analysis was based on a review of data from the European Statistical Office (EUROSTAT), responsible for the publication of high-quality European statistics and indicators that enable the comparison of countries and regions and the monitoring of the main developments in the European energy market, among others. Finally, a list of four important, precisely defined criteria was established. The normalized values of the selected criteria for 2018 are displayed in the cumulative column graph in Figure 2. In addition, input data for 2014-2018 are provided in the GitHub repository as CSV files available at `https://github.com/UserXXXXX/ISD-2021-MCDA-RES-EU`.

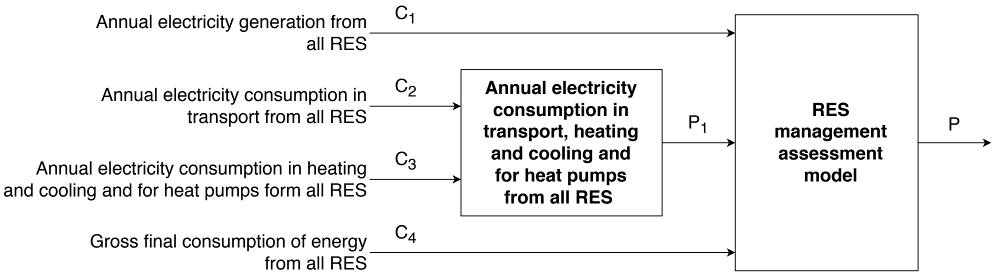
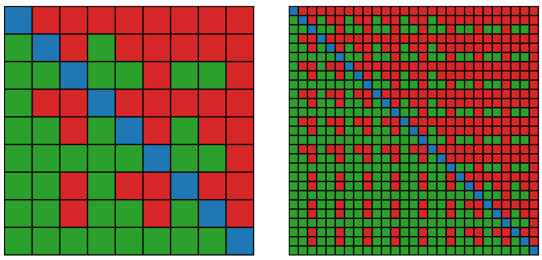


Fig. 3. The hierarchical structure of the RES management in EU assessment problem

Table 1. Values of two different criteria weighting vectors for data from 2018

	C_1	C_2	C_3	C_4
W_{equal}	0.2500	0.2500	0.2500	0.2500
$W_{entropy}$	0.2849	0.2792	0.2105	0.2254



(a) MEJ for P_1 **(b)** MEJ for P

Fig. 4. MEJ matrices calculated for modules P_1 and P for COMET method in 2018

For the COMET method, the considered problem is simplified to a structure, which is illustrated in Figure 3. If a monolithic model without decomposition into modules was used in this case, there would be 3240 comparisons to be performed. After applying hierarchization, their number was reduced to 387. In the case of the model used in this work, criteria C_2 and C_3 have been grouped and are the inputs of the module "Annual electricity consumption in transport, heating and cooling and for heat pumps from all RES", whose output, i.e. P_1, is, in addition to C_1 and C_4, one of the inputs of another module called "RES management assessment model". P is the resulting output of module P_1. For the COMET method procedure, three characteristic values (low, medium and high) were determined for each of the four criteria (C_1–C_4). These values represented the minimum, mean, and maximum values from all alternatives within each criterion. For the TOPSIS method, the criteria weights were determined using objective weighting methods named the equal weights and entropy method [21]. Their values for the 2018 dataset are contained in Table 1.

The MEJ matrices calculated for module P_1 (4a) and P (4b) of the implemented model for the COMET method in 2018 are visualized in Figure 4. Fields coloured green represent a comparison in which the object being compared to another object is more preferred. That is, the value in this field of the MEJ matrix is 1. Red fields mean that the object being compared is less preferred than another object and the field in MEJ has a value of 0. When there is a tie between the compared objects, the value of the MEJ field is equal to 0.5. The colour blue represents this field.

Table 2. Results and positions in rankings of TOPSIS with Equal weights, TOPSIS with weight calculated with Entropy method and COMET in 2018

Symbol	**Country**	**TOPSIS equal**		**TOPSIS entropy**		**COMET**	
		C_i	Rank	C_i	Rank	P_i	Rank
A_1	Belgium	0.1027	16	0.1035	16	0.1816	16
A_2	Bulgaria	0.0613	20	0.0565	20	0.1075	20
A_3	Czechia	0.1215	15	0.1095	15	0.1901	15
A_4	Denmark	0.1509	12	0.1354	14	0.2758	13
A_5	Germany	1.0000	1	1.0000	1	1.0000	1
A_6	Estonia	0.0305	26	0.0260	27	0.0416	27
A_7	Greece	0.0755	18	0.0709	18	0.1519	17
A_8	Spain	0.4237	6	0.4330	6	0.5911	6
A_9	France	0.7144	2	0.6967	2	0.7641	2
A_{10}	Croatia	0.0517	21	0.0468	21	0.0971	21
A_{11}	Ireland	0.0435	24	0.0465	22	0.0765	22
A_{12}	Italy	0.5893	3	0.5729	3	0.7021	3
A_{13}	Cyprus	0.0062	29	0.0052	29	0.0080	29
A_{14}	Latvia	0.0515	22	0.0442	23	0.0763	23
A_{15}	Lithuania	0.0440	23	0.0378	24	0.0598	25
A_{16}	Luxemburg	0.0149	28	0.0161	28	0.0140	28
A_{17}	Hungary	0.0800	17	0.0737	17	0.1076	19
A_{18}	Malta	0.0000	30	0.0000	30	0.0000	30
A_{19}	Netherlands	0.1423	13	0.1493	11	0.2025	14
A_{20}	Austria	0.2527	10	0.2442	9	0.4462	8
A_{21}	Poland	0.2530	9	0.2358	10	0.3630	10
A_{22}	Portugal	0.1411	14	0.1360	13	0.2829	12
A_{23}	Romania	0.1566	11	0.1435	12	0.2949	11
A_{24}	Slovenia	0.0282	27	0.0265	26	0.0529	26
A_{25}	Slovak Republic	0.0363	25	0.0355	25	0.0670	24
A_{26}	Finland	0.3037	8	0.2686	8	0.4350	9
A_{27}	Sweden	0.5190	4	0.5018	4	0.6466	4
A_{28}	United Kingdom	0.4442	5	0.4687	5	0.5867	7
A_{29}	Iceland	0.0621	19	0.0622	19	0.1414	18
A_{30}	Norway	0.3631	7	0.3868	7	0.6110	5

Scores including ranking values and the preference function values calculated using TOPSIS (C_i) and COMET (P_i) for data from 2018 are included in Table 2. Results for 2014–2017 are provided in the GitHub repository available at `https://github.com/UserXXXXX/ISD-2021-MCDA-RES-EU`. Figure 5 presents graphs showing the differences between the rankings obtained using each method. When the aggregate values of the selected criteria are taken into account, it can be seen in Figure 2 that Germany ranks highest in terms of the share of renewables in the electricity sector. Germany has set ambitious climate policy targets for increasing the share of renewable energy and phasing out nuclear power. It was a long process, which underscores the importance of long-term planning in the energy industry with a complex infrastructure [18]. Malta has the lowest position in terms of RES share in energy policy considering the considered criteria. It is due to the quite particular conditions that Malta presents, such as other Mediterranean islands: high population density, limited available land, and ever-increasing electricity demand. For these reasons, on small islands, electricity production shows higher operating costs and losses than on the mainland. The electrical power production is almost completely based on diesel generators in many islands in the Mediterranean Sea [7].

Fig. 5. Comparison of rankings obtained with different MCDA methods in 2018

Table 3. Values of Pearson's correlation coefficient between rankings obtained with TOPSIS with Equal weights, TOPSIS with weights calculated with Entropy method and COMET for 2014–2018

Methods/year	2014	2015	2016	2017	2018
TOPSIS equal/TOPSIS entropy	0.9969	0.9947	0.9956	0.9973	0.9956
TOPSIS equal/COMET	0.9933	0.9933	0.9947	0.9956	0.9915
TOPSIS entropy/COMET	0.9929	0.9947	0.9960	0.9947	0.9933

The presentation of the result rankings allows us to conclude that there is a high convergence between them. Leaders in all rankings remain unchanged. Germany (A_5) is in the highest position in all the rankings received, followed by France (A_9) in second place. The third place was occupied by Italy (A_{12}), and in the fourth position of all rankings was Sweden (A_{27}).

The similarity of the rankings obtained can be objectively estimated using Pearson's correlation coefficient. The rankings obtained for each year studied for the models studied were compared using Pearson's rank correlation coefficient. The results are provided in Table 3. The most consistent rankings are those prepared using TOPSIS with both types of weights, but differences between rankings obtained with TOPSIS and COMET are not significant.

4.1. Sensitivity analysis

This work aimed to investigate the sensitivity of the obtained rankings to changes in the significance of the criteria weights, i.e., sensitivity analysis, and determine what additional useful information related to sustainability it provides. Sensitivity analysis of the rankings was performed. When the problem is observed from various perspectives (electricity generation from all renewable sources (C_1), renewable electricity consumed in transport (C_2), renewable energy consumed in heating and cooling (C_3) and gross final consumption of energy from renewable sources (C_4), the relevance of the different sets of criteria can be seen as different. A sensitivity analysis of the rankings was performed by changing the weight of a single criterion between 0 and 1 by 0.1, while all the remaining criteria had equal values assigned in such a way that the sum of the weights of all criteria is 1 [30]. Sensitivity analysis is used to demonstrate the effect of changes in the values of given model criteria weights on the resulting score. This procedure aims to determine how sensitive the current ranking is to changes in the weights of the decision criteria. Since the results depend on the subjective decisions of the decision-makers, sensitivity analysis can help to construct proposed scenarios that generate more useful information [15]. Sensitivity analysis for changing criteria weights was performed for rankings from 2014–2018. The sample results in the form of graphs of changes in rankings for 2018 are visualized in Figure 6.

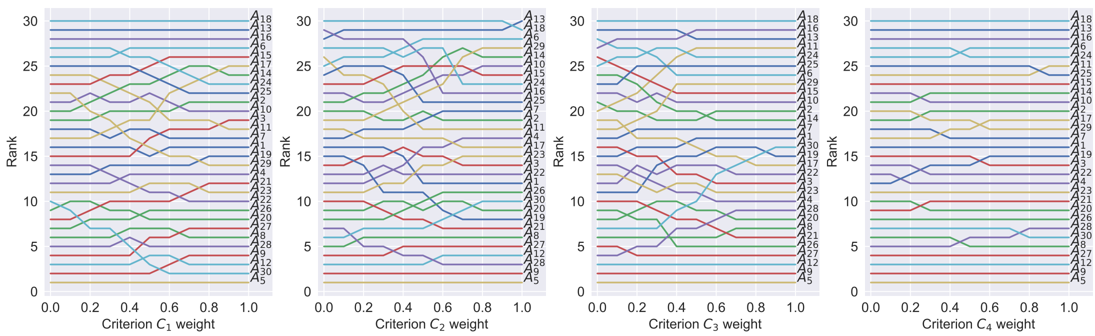


Fig. 6. Sensitivity analysis of studied criteria for TOPSIS in 2018

Results of sensitivity analysis for 2014–2018 are provided in the GitHub repository available at `https://github.com/UserXXXXX/ISD-2021-MCDA-RES-EU`. Summarizing the results of the assessment using the TOPSIS method, we can say that in 2014–2018 growth of C_1's (energy generation from RES) importance has had the most influence on the promotion in the ranking for Norway (A_{30}), Iceland (A_{29}), and Ireland (A_{11}). Increasing the significance of C_2 (consumption of energy from RES in transport) improves the ranking of Ireland, Luxemburg (A_{16}), and the Netherlands (A_{19}), and growth of the relevance of C_3 (consumption of energy from RES in heating and cooling) results in a promotion in the ranking of Latvia (A_{14}) and Estonia (A_6). Decreases in the ranking in 2014–2018 with the growth of importance of C_1's were observed for Hungary (A_{17}). It means that this criterion is not a strongly developed branch in RES management of this country. A similar situation is observed for Iceland with the growth of weight of C_2 and Norway, Ireland, and Iceland with the growth of significance of C_3.

An interesting case observed in the years 2014–2018 that raises special attention are alternatives A_{29} (Iceland) and A_{30} (Norway). In the case of Iceland, we observe a high advance in ranking with the growth of C_1's importance and a big drop with an increase of significance of C_2 and C_3. It means that this country is highly developed in energy generation from RES, but consumption of RES energy in transport or heating and cooling is not significant. Norway advances with the growth of C_1's weight but drops with C_3's weight growth. Another noticeable case is A_{11} (Ireland) that increases in rankings with the growth of C_1 and C_2's weight and drops with the growth of C_3's importance. In contrast, A_{17} (Hungary) decreases in ranking with the growth of C_1's weight but increases with the growth of importance of C_3. It shows differences in the management of RES in various countries.

5. Discussions

The observed results confirm the facts proven in the literature and the authors' assumptions that MCDA methods are suitable as a component of the system for evaluating RES sustainability because they consider multiple criteria and incorporate into the resulting model differing criteria for evaluating individual actions and various assessments and opinions of experts and different interest groups. It was successful in identifying ranking leaders and confirming the stability of their positions.

Various countries differ in their use of RES, and sensitivity analysis enables the identification of these differences and more rational energy policy and economic planning and the evaluation of the achievement of the set goals. In this way, it becomes possible to identify countries' strengths and weaknesses, determine whether there are a need and an opportunity to make progress towards more sustainable development and set appropriate policies in this direction. The study has made it possible to clearly identify the leaders of the rankings, whose positions remain stable over the years studied. The countries with the highest positions in the obtained rankings in terms of the examined criteria include invariably in all examined years Germany, France, Italy, Sweden, and Norway.

6. Conclusions

The aim of this work was an attempt to construct MCDA based decision support system addressing sustainable assessment. As an additional challenge, an autonomic evaluation of alternatives was performed. The paper also shows the practical capabilities of the developed DSS system - as a showcase, the authors have chosen European countries in the economy's main sectors based on EUROSTAT data. It is an important and up-to-date issue due to the ever-increasing significance of renewable energy in the global economy and the need for tools to objectively assess the share of renewable energy sources in the energy markets. The study results significantly confirm a successful attempt to develop a conceptual framework based on MCDA methods and then practical implementation of DSS engine for autonomous evaluation of multi-criteria problems on the example of the problem of using renewable energy sources. The research outcomes confirm that the COMET method enables the effective performance of complex analyses, including multifaceted assessment of sustainable energy policies, and is an alternative to other MCDA methods, such as TOPSIS or AHP. Sensitivity analysis brings additional information about the model, allows planning international exchange and cooperation in renewable energy supply. The authors believe that the proposed system will be a valuable tool for developing systems designed for analyses and rankings in various areas and inspiration for fruitful discussions and further scientific work on its use not only in the management of the energy sector at many levels both within and between countries, but also for multi-criteria problems in other fields.

7. Future work

The study identified shortcomings of the solution as well as directions for further research. The ranking obtained using the COMET method shows a high correlation with the ranking obtained using the TOPSIS method with both types of weights used. The obtained results encourage further research using the innovative COMET method and its advantages. Further future work directions should concentrate on comparing the influence of criteria exclusion on the rankings for the COMET method and other long known MCDA methods (TOPSIS, VIKOR) and the influence of the complexity of the model structure considering the criteria on the results obtained by the COMET method. Perhaps adding a greater amount of input criteria and thus increasing the number of related models could make the final ranking more reliably reflect the varying opportunities for the states evaluated to increase their share of renewable energy in their economy. Further research directions could also include comparing the results obtained using other

MCDA methods, such as PROMETHEE II and SPOTIS.

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