Towards Multi-Criteria Temporal Sustainability Assessment

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Abstract

Multi-criteria decision-making methods have proven their suitability in complex problems of sustainability assessment in different domains. Their main advantage is the capability to simultaneously consider multiple criteria of various dimensions with contrasting objectives. However, these methods assess the current situation at a given moment, whereas sustainability assessment requires considering dynamic changes over time. Thus, the authors of this paper propose a framework based on the Temporal SWARA-SPOTIS method for the temporal evaluation of sustainable development, considering the dynamics of results in long-term observation. The proposed method aggregates the results of the assessments obtained in the different periods, including expert prioritization of the different periods. The practical application of the proposed method involves assessing the sustainability of European countries toward a clean, efficient and affordable energy system.

Keywords

MCDA temporal assessment, SWARA, SPOTIS, sustainability.

Introduction

The Sustainable Development Goal 7 (SDG 7) indicator is an important component of monitoring sustainable development proposed by the United Nations (UN) in Agenda 2030. It is useful in assessing countries regarding universal access to modern energy services, improving energy efficiency with a particular focus on increasing the share of renewable energy sources (RES). A sustainable energy system should be environmentally friendly, affordable, conducive to reducing dependence on imported non-renewable energy sources, and efficient in terms of electricity production (Castor et al. 2020). Multi-Criteria Decision Analysis (MCDA) methods are particularly recommended for reliable sustainability assessment because they fulfill the requirements of considering multiple criteria with contrasting objectives. However, MCDA methods evaluate the current situation based on performance values obtained at a single moment in time. Such an approach for sustainability issues is insufficient as it does not incorporate the dynamics of change over time. This fact became the motivation to propose a framework dedicated to temporal sustainability assessment. This tool is based on the multi-criteria Stable Preference Ordering Towards Ideal Solution method (SPOTIS), the objective criteria weighting technique named MEthod based on the Removal Effects of Criteria (MEREC), and the prioritization of evaluated periods based on the subjective weighting technique Stepwise Weights Assessment Ratio Analysis (SWARA).

The main advantage of the SPOTIS method is its robustness to the phenomenon of ranking reversal when an alternative is added or removed from the evaluated set. This method allows identifying the whole domain model, which is essential in the case of sustainability development assessment. Furthermore, due to its uncomplicated algorithm, it performs well in problems requiring multiple iterations of the algorithm, as in the case of temporal assessment. SPOTIS algorithm is given with details in (J. Dezert et al. 2020). The MEREC method is a novel objective weighting technique. Its novelty arises from using the effect of removing each criterion on the performance of alternatives. The algorithm of this method is presented in detail in (Keshavarz-Ghorabaee et al. 2021). A review of temporal MCDA methods shows that successful adaptation of the TOPSIS method, which consists of a re-assessment of alternatives considering the preference values obtained in each period, is available in the literature (Frini and Benamor 2018). However, the authors do not provide precise rules for determining the significance of particular periods. It became the motivation to address this limitation in the proposed Temporal SWARA-SPOTIS method. For the temporal evaluation using the scores provided by the SPOTIS methods for the following periods, the authors propose an adaptation of the SWARA technique to determine the significance of each evaluated period, the algorithm of which is detailed in (Lombardi Netto et al. 2021). The SWARA technique is a subjective method for determining criterion weights involving the decision-maker based on pairwise comparisons of criteria based on their relative importance. In the proposed approach, the importance of each period is determined based on the strategy chosen by the decision-maker. The analysis aims to assess the sustainability of thirty selected European countries in terms of SDG7 indexes, considering the results achieved during six years.

Methodology

The first step of the proposed approach is the evaluation of alternatives performed individually for each period in time using the SPOTIS method, where criteria significances are determined for each period using the MEREC objective weighting method. The result of the SPOTIS method for each period is a vector containing scores of alternatives weighted normalized average distance values. The resulting vectors with scores are then organized into a decision matrix in which the alternatives are countries, and the criteria are the periods being evaluated. The created matrix is then assessed using the SPOTIS method. Then, periods weights are determined using the subjective SWARA weighting method. In this research, the authors assume that scores registered for the moment closest to the moment of evaluation are more important than scores achieved for earlier periods. The steps of the proposed method are presented below.

The Temporal SWARA-SPOTIS method

Step 1. The first step involves creating a two-dimensional matrix $S = \left[S_{ip}\right]_{m \times t}$ containing in subsequent columns the weighted normalized average distance values determined by SPOTIS for each *i-th* alternative evaluated ($i = 1,2, \dots, m$) in the following *p-th* periods investigated, where $p = 1, 2, \dots, t$. Weighted normalized average distance values are final scores of the SPOTIS method.

Step 2. Rank the periods evaluated in descending order regarding their significance. Period p_1 is the most significant.

Step 3. Determine comparative importance c between investigated periods. Begin with period p_2 and determine how much period p_1 is more important than p_2. In aim to establish c_p provide value from interval [0, 1], which is analogous to percentage. Comparative importance determined between p_1 and p_2 is denoted by c_1. Follow the same procedure up to period p_t. Comparative importance established between p_{t-1} and p_t is represented by c_{t-1}.

Step 4. Calculate the coefficient k_p as Equation (1) presents.

$$k_p = \begin{cases} 1, \ p = 1 \\ c_p \ + \ 1, \ p > 1 \end{cases} \qquad (1)$$

Step 5. Determinate initial periods weights v_p according to Equation (2).

$$v_p = \begin{cases} 1, \ p = 1 \\ \frac{v_{p-1}}{k_p}, \ p > 1 \end{cases} \qquad (2)$$

Step 6. Calculate final periods weights w_p as Equation (3) shows.

$$w_p = \frac{v_p}{\sum_{p=1}^{t} v_p} \qquad (3)$$

Step 7. The last three steps include evaluating matrix S containing weighted normalized average distance values of alternatives calculated for each period p with the SPOTIS method. First, determine the normalized distances d_{ip} for alternatives A_i from Ideal Solution Point S^* as Equation (4) presents. S^{min} represents S^*

here because the algorithm of the SPOTIS method ranks alternatives in ascending order according to weighted normalized average distance values obtained for each period. Thus, an alternative with the lowest normalized average distance value is the best-scored option.

$$d_{ip}(A_i, s_p^*) = \frac{|S_{ip} - S_p^*|}{|S_p^{max} - S_p^{min}|} \quad (4)$$

Step 8. Calculate the weighted normalized average distance values according to Equation (5).

$$d(A_i, s^*) = \sum_{p=1}^{t} w_p \, d_{ip}(A_i, s_p^*) \quad (5)$$

Step 9. Create a final ranking of alternatives covering the whole analyzed time by sorting $d(A_i, s^*)$ ascendingly, according to the SPOTIS algorithm. The best-scored variant is an alternative that received the lowest $\mathrm{d}(A_i, s^*)$ value.

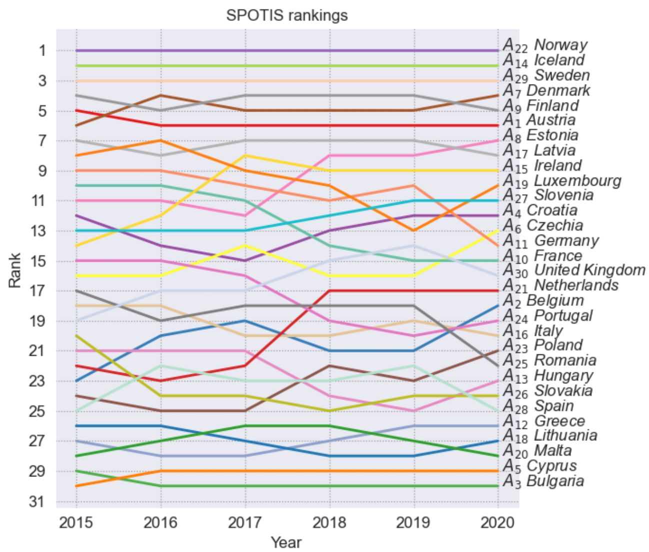
Dataset

This paper aims to present a framework for reliable temporal assessment of sustainable development in European countries in terms of SDG 7, the Sustainable Development Goal of UN's Agenda 2030, focused on affordable and clean energy. This indicator includes eleven criteria, where ↑ represents the aim of maximizing and ↓ denotes the aim of minimizing criteria performance value. Criteria set is represented by C = {C_1 – Primary energy consumption (Tonnes of oil equivalent TOE per capita, ↑), C_2 – Final energy consumption (Tonnes of oil equivalent TOE per capita, ↑), C_3 – Final energy consumption in households per capita (Kilogram of oil equivalent KGOE, ↑), C_4 – Energy productivity (Euro per kilogram of oil equivalent KGOE, ↑), C_5 – Share of RES in gross final energy consumption in general (%, ↑), C_6 – Share of RES in gross final energy consumption in transport (%, ↑), C_7 – Share of RES in gross final energy consumption in electricity (%, ↑), C_8 – Share of RES in gross final energy consumption in heating and cooling (%, ↑), C_9 – Energy import dependency regarding all types of energy products (solid fossil fuels, oil and petroleum products excluding biofuel portion, natural gas (%, ↓), C_{10} – Population unable to keep home adequately warm (%, ↓), C_{11} – Greenhouse gas emissions intensity of energy consumption (Index, 2000=100, ↓)}. The set of assessed alternatives includes countries shown in Figure 1. Performance values of evaluated countries regarding criteria included in SDG 7 were acquired from the Eurostat dataset (access date: 26 February 2022) for the six years 2015-2020 to be analyzed.

Results and Discussion

This section provides the temporal analysis of European countries regarding affordable and clean energy measured with SDG 7. Figure 1 displays changes in SPOTIS rankings of 30 evaluated countries generated for each year. It can be observed that only three countries among the thirty examined over the six years reviewed remain unchanged. These stable countries are the ranking leaders, which include Norway (A_{22}) in the first place, Iceland (A_{14}) in second place, and Sweden (A_{29}), which is in third place. However, there is significant variability in the rankings among the remaining countries. The largest variability covering a range of six positions was noted for Ireland (A_{15}), Luxembourg (A_{19}), and the Netherlands (A_{21}). Ireland shows a trend of significant improvement in the sustainability aspect focused on affordable and clean energy, which is demonstrated by moving up to eighth place in 2016 from 14th place held in 2015. Then, it consistently ranked 9th from 2017 to 2020. The Netherlands also showed a noticeable trend of improvement. This country climbed to 17th place in 2018 from the 23rd place occupied in 2016. However, a worsening trend was demonstrated by Luxembourg, which dropped to 13th place in 2019 from the 7th place taken in 2016. The method proposed in this paper for adequately assessing the significant variability in scores received by alternatives at any given time proves extremely useful, mainly when, as in the example presented here, it even implies a range of more than five positions in the rankings. Table 1 shows the results obtained in the subsequent steps of the procedure for determining the significance of particular periods using the SWARA method. The illustrative example presented in this paper uses a strategy where each successive year is 50% more relevant than the previous year. In practice, decision-makers can set s_p values according to expert knowledge individually for the problem under solution. The ranking of the Temporal SWARA-SPOTIS (TSS) method compared to benchmarking ranking generated for averaged data from all periods (AVG) is contained in Table 2. Stable leaders in subsequent years remain in the top three positions. It is worth noting the results obtained by the countries with the highest variability.

Figure 1. Rankings of SPOTIS method for investigated periods.



Period	c_p	k_p	v_p	w_p
2020	0.0	1.0	1.0000	0.3654
2019	0.5	1.5	0.6667	0.2436
2018	0.5	1.5	0.4444	0.1624
2017	0.5	1.5	0.2963	0.1083
2016	0.5	1.5	0.1975	0.0722
2015	0.5	1.5	0.1317	0.0481

Table 1. Results of periods weights determination by SWARA method.

A_i	AVG	TSS	A_i	AVG	TSS	A_i	AVG	TSS	A_i	AVG	TSS	A_i	AVG	TSS
A_1	6	6	A_7	5	5	A_{13}	24	24	A_{19}	9	10	A_{25}	18	20
A_2	21	21	A_8	8	8	A_{14}	2	2	A_{20}	28	28	A_{26}	25	25
A_3	30	30	A_9	4	4	A_{15}	10	9	A_{21}	19	18	A_{27}	12	11
A_4	13	13	A_{10}	14	14	A_{16}	20	19	A_{22}	1	1	A_{28}	22	23
A_5	29	29	A_{11}	11	12	A_{17}	7	7	A_{23}	23	22	A_{29}	3	3
A_6	16	15	A_{12}	27	26	A_{18}	26	27	A_{24}	17	17	A_{30}	15	16

Table 2. Ranking of Temporal SWARA-SPOTIS compared with the average ranking.

Ireland (A_{15}) ranked 9th in the Temporal SWARA-SPOTIS ranking. The proposed method reflects the progressive improvement in Ireland's performance over the years examined more accurately than a ranking based on performance averages, in which Ireland was ranked 10th. A similar situation is observed in the case of the Netherlands (A_{21}), which, due to the previously described progressive advancement in subsequent years, was finally ranked 18th in the Temporal SWARA-SPOTIS ranking. In contrast, in the ranking for averaged data, this country was ranked 19th. Luxembourg (A_{19}), for which a worsening of performance in successive years was observed, ranked 10th in the Temporal SWARA-SPOTIS and 9th in the ranking from averaged performances. Thus, it is evident that the proposed method adequately represents the progress or regression of alternatives in subsequent years according to their relevance. Table 3 demonstrates that correlation of the ranking obtained by the Temporal SWARA-SPOTIS method with rankings generated for subsequent years measured by Weighted Spearman's Rank Correlation Coefficient r_w increases more consistently regarding the assumed increase in the significance of following years than the benchmark SPOTIS ranking for averaged data. Higher values of r_w coefficient imply higher convergence between compared rankings. The obtained results confirm that applying the method proposed in the paper is reasonable and practical in the temporal evaluation of sustainable development in any aspect and beyond. From a practical point of view, the proposed method for assessment of sustainability in terms of SDG7 indexes is essential because it enables the consideration of results collected for a long-term observation period, provides the opportunity to prioritize considered periods according to the priorities of decision-makers, and stakeholders, and enables the inclusion of multiple assessment criteria. The complete data and results are provided at https://github.com/energyinpython/AMCIS-2022-SWARA-SPOTIS .

Year	2015	2016	2017	2018	2019	2020
TSS	0.9670	0.9740	0.9817	0.9969	0.9917	0.9921
AVG	0.9736	0.9808	0.9840	0.9972	0.9907	0.9851

Table 3. Correlation of Temporal SWARA-SPOTIS and average rankings with 2015-2020.

Conclusion

The paper addresses the up-to-date topic of sustainability assessment and contributes to the mainstream research branch oriented on MCDA methods-based assessments. The main advantage of the paper is to propose a dynamic MCDA approach for better reflecting sustainability assessment than classical MCDA methods, which is confirmed by the research mentioned above. Multi-criteria sustainability assessment considering several criteria and dynamics over time requires reliable methods allowing aggregation of results received over time with appropriate prioritization of periods. The Temporal SWARA-SPOTIS method presented in this paper evaluates alternatives across periods and aggregates results over time after assigning period significance. The results obtained demonstrated the usefulness and reliability and adequately reflected the dynamics of change over time. As the paper presents preliminary research, our approach requires more profound research in terms of model complexity and methodologically - investigation towards reliability and robustness of results in the light of other MCDA methods. Nevertheless, the results encourage further research involving multi-criteria sustainability assessment requiring consideration of the dynamics over time. Among the directions for future work, the authors indicate the use of the proposed Temporal SWARA-SPOTIS method for multi-criteria temporal evaluation of other SDGs included in the UN's 2030 Agenda for sustainable development.

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