

# Towards Temporal Multi-Criteria Assessment of Sustainable RES Exploitation in European Countries

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**Abstract**—This paper aims to introduce a novel Temporal SWARA-SPOTIS method for multi-criteria temporal assessment. The proposed method combines the Step-Wise Weights Assessment Ratio Analysis (SWARA) method for determining the significance values of particular periods and the Stable Preference Ordering Towards Ideal Solution (SPOTIS) method for the multi-criteria assessment. The developed method was applied for assessing the sustainable use of renewable energy sources (RES) by European countries in various branches of the economy and industry, considering multiple criteria and the dynamics of results change over time. The application of the proposed method is presented in an illustrative example covering the assessment of 30 selected European countries over the five years 2015-2019. The presented approach proved its usefulness in the problem investigated and provided reliable results indicating that the best-scored countries regarding sustainable use of RES are dominantly the Nordic countries.

## I. INTRODUCTION

**R**ENEWABLE energy sources (RES) play an essential role in the sustainable economy. The increase in RES participation in various domains contributes to limiting greenhouse gas and pollutants emissions and reducing countries' dependence on imports of non-renewable energy sources. The efforts to increase the RES share cover different dimensions. Among them is electricity generation from RES such as Hydro, Wind, Solar, Biomass, Geothermal, and Wave (tidal). Besides, energy policies promoting RES usage include increasing the RES share in energy consumption in transportation and heating and cooling sectors. Thus, appropriate measurement tools are necessary to assess the achievement of planned goals and evaluate regions [1].

Reliable assessment of sustainable RES use requires simultaneous consideration of dimensions such as economic, environmental, and social [1]. The assessment methodology for multi-criteria RES problems should consider different aspects, such as various types of RES, several attributes of the location for RES-generating infrastructures, and different sectors in which RES are produced and consumed [2]. Multi-criteria decision analysis methods (MCDA) fulfill these requirements [3]. Many research papers are focused on evaluating RES problems. Multi-criteria assessment of countries in terms of preparation for the sustainable energy transition was performed using Preference Ranking Organization Method for Enrichment of Evaluation (PROMETHEE) II and Analytical Hierarchy Process (AHP) [1]. A comparative analysis

employing Characteristic Objects Method (COMET), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR), and PROMETHEE II, was conducted to assess the European countries in terms of energy consumption with particular attention to RES share [3]. MCDA methods were applied to evaluate infrastructure and technologies for generating electricity from RES. COMET and Stable Preference Ordering Towards Ideal Solution (SPOTIS) were used to evaluate solar panel alternatives regarding selected technical attributes of assessed options [4].

The literature review confirms the usefulness of MCDA methods in the multi-dimensional evaluation of RES for a single moment. However, a clear research gap is visible, including the lack of simultaneous respect for the performance variability over the time analyzed. Several MCDA attempts of temporal approach can be found in the literature, like the TOPSIS-based approach considering the variability of results over time. This approach considers evaluating alternatives using TOPSIS individually for each analyzed year. Results are re-evaluated using TOPSIS and weights assigned to years [5]. The authors of another research adapted the PROMETHEE II method to perform a multi-criteria evaluation of temporal sustainable forest management [6]. This approach aggregates the results of comparing pairs of criteria in each period. The rank relations are converted to preference relations for each pair of alternatives and each period in the next stage. However, the procedure described is complex, making applying to complex hierarchical models containing multiple criteria challenging. This paper introduces the Temporal SWARA-SPOTIS method developed for multi-criteria temporal evaluation. The application of the proposed method is illustrated in the example of a temporal multi-criteria assessment of selected European countries in terms of RES use in various branches of the economy and industry.

The rest of the paper is organized as follows. Section II gives the background and formulas for SWARA-SPOTIS. The following section III introduces the practical problem of sustainability assessment focused on RES exploitation by European countries is introduced. The next section IV presents and discusses research results. Finally, in the last section V conclusions are provided, and future work directions are drawn.

## II. METHODOLOGY

### A. The Temporal SWARA-SPOTIS method

**Step 1.** Create the temporal decision matrix  $S = [s_{ip}]_{m \times t}$  including in columns the utility function values (weighted normalized average distance values) calculated by SPOTIS for each  $i$ th alternative  $i = 1, 2, \dots, m$  in  $p$ th periods analyzed, where  $p = 1, 2, \dots, t$ . The SPOTIS steps are presented in [7]. In this research criteria weights were determined using objective weighting method called CRITIC demonstrated in [8].

**Step 2.** This step involves determining the significance of particular periods using SWARA [9]. Rank periods in descending order according to their significance. Period  $p_1$  is the most significant.

**Step 3.** Establish comparative importance ratio  $c$  among investigated periods. Start with the period  $p_2$  and define how much period  $p_1$  is more significant than  $p_2$ . Determine  $c_p$  ratio using values in the range from 0 to 1, analogously to percentage. Value of comparative importance ratio  $c_1$  is determined for periods  $p_1$  and  $p_2$ . Then, identical procedure is followed up to period  $p_t$ . Comparative importance determined between  $p_{t-1}$  and  $p_t$  is denoted by  $c_{t-1}$ , where  $t$  represents number of all periods to investigate.

**Step 4.** Compute the coefficient  $k_p$  values according to Equation (1), where  $p$  represents periods ranked in descending order according to their importance.

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

**Step 5.** Calculate initial weights  $v_p$  for particular periods as Equation (2) presents.

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

**Step 6.** Determine final SWARA weights  $w_p$  for each period according to Equation (3).

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

**Step 7.** The three final stages involve the Temporal SWARA-SPOTIS assessment of matrix  $S$  including SPOTIS utility function values  $s$  in the form of weighted average distance values calculated for alternatives for each period  $p$ . First step includes determination of the normalized distances  $d_{ip}$  for each alternative  $A_i$  from Ideal Solution Point  $S^*$  according to Equation 4.  $S^*$  is represented by  $S^{min}$  since the SPOTIS creates rankings by sorting alternatives in ascending order, considering utility function values received by alternatives in each period. Alternative with the lowest utility function value is regarded as the best-evaluated option.

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

**Step 8.** Compute the final temporal utility function values for each alternative as Equation (5) shows

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

where  $w_p$  represents SWARA weights assigned for particular periods.

**Step 9.** Generate the final Temporal SWARA-SPOTIS ranking of evaluated alternatives involving the full investigated time by sorting values  $d(A_i, s^*)$  obtained in the previous step in increasing order. The best-evaluated option has the lowest  $d(A_i, s^*)$  value. Rankings are compared using two correlation coefficients: Weighted Spearman rank correlation coefficient  $r_w$  described in [4] and Spearman rank correlation coefficient detailed in [10]

## III. THE PRACTICAL PROBLEM OF EUROPEAN COUNTRIES' CONSIDERING TEMPORAL ASSESSMENT OF RES USAGE

The framework for temporal assessment of sustainable RES using is based on annual data provided by Eurostat in a database collected with the SHARES (SHort Assessment of Renewable Energy Sources) tool [11]. Particular criteria are included in Table I.

TABLE I  
CRITERIA FOR SUSTAINABLE RES USING ASSESSMENT.

$C_j$	Criterion name	Goal	Unit
$C_1$	Annual electricity generation from Hydro	Max	[% of E]
$C_2$	Annual electricity generation from Wind	Max	[% of E]
$C_3$	Annual electricity generation from Solar	Max	[% of E]
$C_4$	Annual electricity generation from Solid biofuels	Max	[% of E]
$C_5$	Annual electricity generation from all other renewables	Max	[% of E]
$C_6$	Annual consumption of renewable electricity in road transport	Max	[% of T]
$C_7$	Annual consumption of renewable electricity in rail transport	Max	[% of T]
$C_8$	Annual consumption of renewable electricity in all other transport modes	Max	[% of T]
$C_9$	Annual consumption of renewable electricity from compliant biofuels in transport	Max	[% of T]
$C_{10}$	Annual final energy consumption in heating and cooling	Max	[% of H&C]
$C_{11}$	Annual derived RES based heat in heating and cooling	Max	[% of H&C]
$C_{12}$	Annual derived RES based heat in heating and cooling for heat pumps	Max	[% of H&C]
$C_{13}$	Gross final consumption of energy from renewable sources in electricity	Max	[% of G]
$C_{14}$	Gross final consumption of energy from renewable sources in heating and cooling	Max	[% of G]
$C_{15}$	Gross final consumption of energy from renewable sources in transport	Max	[% of G]

There are criteria covering generation of electricity from RES ( $C_1$ – $C_5$ ) and its consumption ( $C_6$ – $C_{15}$ ). Data in the mentioned database are available in the unit KTOE (Thousand tonnes of oil equivalent). However, in an attempt to provide a more reliable and objective assessment, this research employed percentage data representing the share of each measure in each sector. This approach enables the reduction of inequalities between the countries caused by non-modifiable factors such

as area, geographical location, and population, which objectifies the assessment. Therefore, this framework considers RES percentage share in sectors considering all energy sources, such as electricity production (E), energy consumption in transport (T), heating and cooling (H&C), and gross final energy consumption (G). The goal of each criterion is maximization because the assumption of sustainable development is to increase the share of RES in all sectors.

Performance values in the form of percentages of criteria representing the use of RES in particular sectors for 2015–2019 are available in the GitHub repository at [12] in a dataset folder. The results of a multi-criteria temporal assessment concerning sustainable RES are presented in the following section IV.

#### IV. RESULTS

This section presents the results of the temporal multi-criteria assessment of RES exploitation in European countries performed by the SWARA-SPOTIS method. Criteria weights were determined for each year using the CRITIC method. Then, each decision matrix was evaluated by the SPOTIS method. Next, a decision matrix containing utility function values obtained by countries in each year was created. The next step was determining the significance values for each period using the SWARA method. Then, a decision matrix including SPOTIS utility function values for each year was evaluated using the SWARA weights. The resulting vector with Temporal SWARA-SPOTIS utility function values for each country aggregates annual results into a single score. The obtained Temporal SWARA-SPOTIS utility function values were then ranked in ascending order, according to the SPOTIS rule. It can be observed that Sweden ( $A_{27}$ ) is the leader of both rankings in all years analyzed. Thus, Sweden is expected to be the ranking leader aggregating the grades achieved in the analyzed period. For the other countries, performing a reliable assessment incorporating the dynamics of performance changes over time is no longer straightforward and intuitive. Instead, it requires using an appropriate methodology, such as Temporal SWARA-SPOTIS. Table II contains the results of the subsequent stages of the SWARA method applied to determine the significance of particular periods.

TABLE II  
SWARA WEIGHTS OF PARTICULAR YEARS INVESTIGATED.

Year	$c_p$	$k_p$	$v_p$	$w_p$
2019	-	1	1.0000	0.3839
2018	0.5	1.5	0.6667	0.2559
2017	0.5	1.5	0.4444	0.1706
2016	0.5	1.5	0.2963	0.1137
2015	0.5	1.5	0.1975	0.0758

The most recent year is considered the most significant, while for the earlier years, the significance gradually decreases. In applied strategy, each subsequent year is 50% more significant than the year preceding. The advantage of the proposed method is that the decision-maker can arbitrarily

model the relevance of each period by setting values of comparative importance ratio  $c_p$  for each period. It implies that 2016 is 50% more significant than 2015. For subsequent years, the procedure is analogous. Column  $w_p$  contains the final SWARA weights calculated for each period  $p$ . Table III includes annual SPOTIS rankings calculated for each country in each period. Columns "TSS" contain rankings provided by the Temporal SWARA-SPOTIS method. Scores (utility function values) of SPOTIS are provided on [12] in folder called results.

TABLE III  
RESULTS OF CLASSICAL SPOTIS AND TEMPORAL SWARA-SPOTIS FOR 2015–2019.

$A_i$	Country	2015	2016	2017	2018	2019	TSS
$A_1$	Belgium	24	22	23	24	24	24
$A_2$	Bulgaria	12	14	16	14	15	14
$A_3$	Czechia	16	18	20	20	20	19
$A_4$	Denmark	6	4	3	2	2	3
$A_5$	Germany	10	10	11	11	11	11
$A_6$	Estonia	13	11	12	10	10	10
$A_7$	Greece	14	15	10	12	12	12
$A_8$	Spain	17	13	13	15	14	13
$A_9$	France	18	19	19	21	19	20
$A_{10}$	Croatia	19	17	18	18	17	17
$A_{11}$	Ireland	29	29	28	30	30	30
$A_{12}$	Italy	7	7	7	9	8	7
$A_{13}$	Cyprus	27	26	24	17	21	23
$A_{14}$	Latvia	9	9	9	8	9	9
$A_{15}$	Lithuania	15	16	17	19	22	18
$A_{16}$	Luxembourg	28	28	30	29	29	29
$A_{17}$	Hungary	22	24	25	25	26	26
$A_{18}$	Malta	23	20	15	13	13	15
$A_{19}$	Netherlands	30	30	29	27	27	27
$A_{20}$	Austria	2	2	4	3	3	2
$A_{21}$	Poland	25	27	27	28	28	28
$A_{22}$	Portugal	5	5	6	6	6	6
$A_{23}$	Romania	11	12	14	16	16	16
$A_{24}$	Slovenia	20	21	21	22	23	21
$A_{25}$	Slovakia	21	25	26	26	25	25
$A_{26}$	Finland	3	6	5	5	5	5
$A_{27}$	Sweden	1	1	1	1	1	1
$A_{28}$	United Kingdom	26	23	22	23	18	22
$A_{29}$	Iceland	8	8	8	7	7	8
$A_{30}$	Norway	4	3	2	4	4	4

As expected, Sweden ( $A_{27}$ ) is the best-scored country regarding the sustainable share and use of RES. Austria ( $A_{20}$ ) took second place. Austria ranked second in 2015 and 2016, dropped to fourth in 2017, and ranked third in 2018 and 2019, despite the worsening performance in 2017–2019. However, the Temporal SWARA-SPOTIS method employs the utility function values obtained in the individual years as performance values, which are more precise than ranks. This feature allows for a more accurate and reliable reflection of the aggregate performance of the countries over the years reviewed. Denmark achieved third place ( $A_4$ ). This country improved the use of RES in the economy over the years analyzed. It ranked sixth in SPOTIS in 2015, then jumped to fourth place in 2016. In 2017, there was a further promotion of Denmark to third place. In 2018, Denmark again climbed to second place and remained there in 2019. Because most recent years are more relevant, the promotions registered between

2017 and 2019 allowed Denmark to reach the third position in the final ranking despite the sixth place occupied in 2015. Norway ( $A_{30}$ ) took fourth place in the final ranking. Norway in 2015 was fourth. In 2016, Norway moved up to third place and in 2017 to second place. However, it was again ranked fourth in 2018 and 2019. The greater importance of most recent years caused the better performance in 2016-2017 did not enable Norway to rank higher than fourth in the final ranking. Finland ( $A_{26}$ ) received fifth place in the final ranking. This country was ranked third in 2015. Then in 2016, Finland dropped to sixth place. In contrast, Norway advanced to fifth place in 2017. Therefore, this country retained a fifth place in the remaining years analyzed. Table IV contains the values of the correlation coefficients  $r_w$  and  $r_s$  representing the convergence of the final aggregated rankings obtained using Temporal SWARA-SPOTIS with the SPOTIS rankings generated for the individual years analyzed. High values of both correlation coefficients close to 1 indicate high convergence of the compared rankings.

TABLE IV  
CORRELATION OF TEMPORAL SWARA-SPOTIS WITH SPOTIS.

Year	2015	2016	2017	2018	2019
$r_w$	0.9562	0.9835	0.9912	0.9885	0.9906
$r_s$	0.9448	0.9795	0.9907	0.9867	0.9884

The results confirm that the Temporal SWARA-SPOTIS ranking is more convergent with the most recent analyzed years, 2017-2019, than with the earlier years, 2015-2016. Results are consistent with the assumption that the most recent years are more interesting for decision-makers and reflect appropriately the influence of the weights assigned to the following years by the SWARA method.

## V. CONCLUSIONS

This paper demonstrated the application of the newly developed Temporal SWARA-SPOTIS method on the illustrative example of a multi-criteria problem involving evaluating the sustainable use of RES by European countries, considering the dynamics of performance variability over the observed five years. The developed methodology indicated Sweden as the most sustainable country among the investigated European countries. Likewise, other Nordic countries such as Denmark, Norway, and Finland are among the best-ranked countries. Austria is also a well-scored country. The proposed tool has a high potential of usefulness for information systems supporting multi-criteria sustainability assessment taking into account both multiple indicators and dimensions and the variability of results over time.

The proven usefulness of the proposed tool suggests extending the conducted research to explore other MCDA methods and techniques for determining the relevance of periods. An interesting future work direction seems to be an approach adapting the PROMETHEE II method for multi-criteria temporal sustainability assessment. This method appears promising due to its ability to employ different preference functions

and limited criteria compensation. Further research focused on temporal multi-criteria sustainability assessment is also planned to include a study of the impact of other objective criteria weighting methods on the results. Investigating the utility of the proposed sustainability assessment approach based on other RES indicators may also be an interesting research direction.

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