A TOPSIS-based approach for wind turbines ranking with negative performance ratings and different weighting strategies

Dănuţ Zahariea[1,*], *Dorin Emil* Husaru[1], and *Mihai Silviu* Pavăl[1]

[1]"Gheorghe Asachi" Technical University of Iasi, D. Mangeron No. 67, 700571, Iasi, Romania

Abstract. This paper presents an application of TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) multi-dimensional criteria decision-making method for a case study related with a wind turbine based on-grid power supply system with negative performance ratings and different weighting strategies. Two wind turbines (XZ and XL) are comparatively analysed with respect to a power supply system for an industrial consumer and a given site. The site wind potential has been obtained from NASA Surface meteorology and Solar Energy database. The on-grid power supply system has been modelled and simulated using HOMER Pro software. Ten attributes have been considered: five technical criteria, four financial criteria and one environmental criterion. Eleven different weighting strategies have been considered. From all these weighting strategies, the XZ wind turbine has been selected in 8 cases while the XL wind turbine has been selected in 2 cases. For two particular weighting strategies, the most suitable alternative (XZ) coincides with the ideal solution, while the other alternative (XL) coincides with the negative ideal solution.

1 Introduction

Very often, during the process of renewable projects development, particularly for wind power projects, there are situations which involve choosing one alternative from several possible, by comparing the alternatives under a certain set of weights. One of the most important such situations is the selection of the most suitable wind turbine for a certain site [1-3].

The selection of the most suitable alternative is generally based on multi-criteria decision making (MCDM) analysis. The main steps of an MCDM analysis are: selecting the alternatives, defining the criteria which will be used for comparing the alternatives, defining the specific weighting strategy of criteria evaluation by importance, computing the rank order of the alternatives and obtaining of the most preferred alternative by using a specific MCDM method [4, 5]. The most important MCDM methods are [4, 5]: weighted sum method [2]; weighted product method [6]; analytical hierarchy process [1]; analytical network process; fuzzy analytical network process [3]; interpretive structural modelling [3]; technique for order of preference by similarity to ideal solution; elimination and choice expressing reality.

The weighted product method has been used in [6] for selection of the most suitable wind turbine between two alternatives, based on a single weighting strategy and nine criteria, of which five are technical criteria (annual energy production, wind turbine capacity factor, renewable fraction, grid purchase and grid sales) and four are financial criteria (net present cost, cost of energy, initial investment and simple payback). At the beginning of that study, the 10th criterion (environmental type) has been also proposed: CO_2 emission. According with the HOMER calculations, for an on-grid power supply

system, the CO_2 emission [t/year] is calculated with the formula [7]:

$$CO_2 = (G_p - G_s) f_{CO_2} \qquad (1)$$

where G_p [kWh/year] and G_s [kWh/year] are the total grid purchases and the total grid sales, and f_{CO_2} [t/kWh] is the CO_2 emission factor. If $G_p < G_s$, the grid-related emission of CO_2 is negative.

During that analysis, this particular situation has been noticed, and negative values of the 10th criterion have been obtained. As a consequence of the fact that the authors did not find a way to handle these negative values with weighted product method, the 10th criterion has been removed from the criteria list and the decision process has been made based only on the rest of nine criteria. But the problem remains: handling negative performance ratings in the general context of MCDM analysis.

In this paper a similar wind power project will be presented, with the same two wind turbines as alternatives, but for a different site and a different consumer. Moreover, in this case study the criteria list will includes also the 10th criterion, but a different MCDM method will be used: the TOPSIS method [5].

One sensitive parameter related with the consumer will be defined. For some values of this sensitive parameter, the 10th criterion will have both negative values, or both positive values, or, finally, one negative value and the other, positive value.

To analyse the influence of weighting strategy, eleven weighting strategies will be considered: five strategies based on technical, financial and environmental criteria; two strategies based only on technical and financial criteria, two strategies based only on financial and

---
* Corresponding author: dzahariea@yahoo.com

environmental criteria, and two strategies based only on technical and environmental criteria.

2 Case study

Let us consider a power supply system composed by a wind turbine on-grid connected which will supply electricity for a single consumer. Considering the proposed wind turbine site, the wind resources will be obtained. Two different wind turbines will be analysed for the same site in order to supply electricity for the same consumer: XZERES 10 kW (XZ) [8], and Bergey Excel 10 kW (XL) [9]. The computations have been performed using HOMER Pro software (Hybrid Optimization of Multiple Energy Resources) [7].

2.1 Site location and wind resources

The wind turbine site is located in Denmark, on the North Sea shore, between Hamborg and Febbbersted, at the coordinates 57.1162556 and 8.6622306. The wind and temperature resources for the proposed site have been obtained from NASA Surface meteorology and Solar Energy database (NASA Langley Research Centre Atmospheric Science Data Centre Surface meteorological and Solar Energy (SSE) web portal supported by the NASA LaRC POWER Project) [10].

The wind speed at 50 m height is presented in Figure 1. The maximum wind speed is 8.66 m/s in January, while the minimum wind speed is 5.32 m/s in June, and the annual average wind speed is 6.91 m/s. The reference wind speed for the proposed site is obtained at the reference height of 50 m, while the standard hub height for both wind turbines is 24.4 m [8, 9]. For extrapolating the wind speed at the hub height, the wind speed logarithmic profile is used.
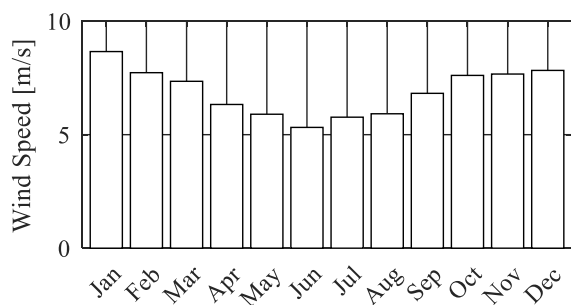

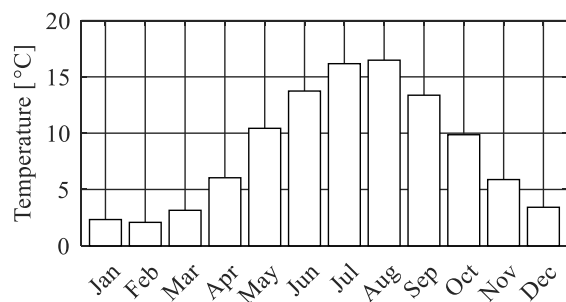**Fig. 1.** Monthly average wind speed at 50 m.

Fig. 2. Monthly average temperature.

The temperature for the selected site is presented in Figure 2. The maximum temperature is 16.48 °C in August, while the minimum temperature is 2.08 °C in February, the temperature range is 14.4 °C, and the annual average temperature is 8.58 °C.

2.2 Electric load

Let us consider that the wind turbine on-grid connected power supply system will be used for supply electricity for an industrial consumer with a daily maximum primary load of 100 kWh/day.

HOMER provide load profiles templates for different types of consumers: residential, commercial, industrial and community [7]. For this case study, the industrial load profile has been selected, the average load has been scaled to 100 kWh/day and some random variability has been introduced by day-to-day and timestep parameters. In order to ensure a reliable electricity supply, despite variability in load and renewable power output, the operating reserve is considered in HOMER calculations by 10% of load in current time step, as well as by 50% of renewable output. In this way, the power supply system will be able to have enough spare operating capacity to serve a sudden 10% increase in the load, as well as a sudden 50% decrease in wind turbine output.

Under these circumstances, HOMER will obtain the consumer electric load which can be expressed, for example, by seasonal load profile presented in a box and whisker plot format in Figure 3.
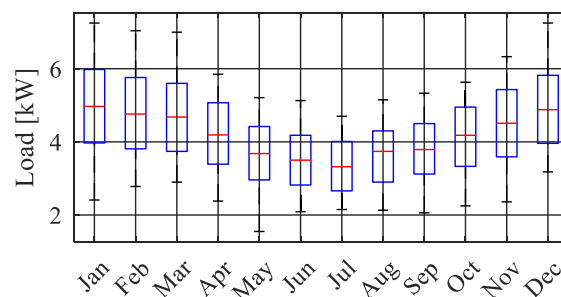

Fig. 3. Seasonal load profile.

The top and bottom lines correspond to the overall maximum and minimum for each month. The top and the bottom of the blue box correspond to the average daily maximum and minimum of all of the days in each month. Finally, the middle red lines correspond to the overall average for the whole month. Figure 3 shows the peak load of 7.25 kW for January and December while the computed average will be 4.17 kW with a load factor of 0.57.

Let us consider that the industrial consumer will work at different production levels, defining in this way the consumer power load level as a sensitive parameter. Moreover, let us assume the following values for this sensitive parameter {60; 70; 80; 90; 100} % for which the daily average load will be {60; 70; 80; 90; 100} kWh/day, and the annual average load will be {21.9; 25.55; 29.2; 32.85; 36.5}$\cdot 10^3$ kWh/year.

2.3 On-grid power supply system

The power supply systems are composed by the consumer, the grid, and the wind turbine (XZ or XL), Figure 4, a). These two power supply systems will be comparatively analysed with respect to the reference power supply system, based only on the grid, Figure 4, b).
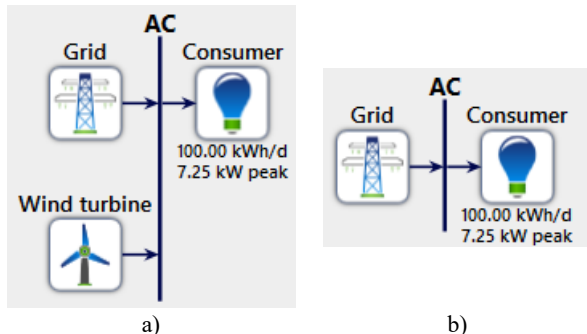

a)   b)

Fig. 4. The power supply system.

For this case study, the principal characteristics of the power supply system are: 20 years lifetime; 8% nominal discount rate; 2% expected inflation rate; 0.28 €/kWh grid power price; 0.2 €/kWh grid sellback price; 25 €/tCO$_2$ carbon dioxide penalty. For Denmark, the electricity price, with all taxes included, has been obtained from EUROSTAT database, for non-household consumers in consumption band IB, 20 MWh÷500 MWh, for the 2nd semester of 2017 [11], while the carbon dioxide penalty has been obtained from [12].

2.4 Numerical results

All parameters discussed above represent input data for a HOMER project file which has been calculated for each value of production level. In order to comparatively analyse the wind turbine power supply systems with respect to the reference case based only on the grid, three types of attributes have been considered and computed with HOMER software:

- Technical criteria, (T): T1: Annual Energy Production, AEP [kWh/year]; T2: Wind turbine capacity factor [%]; T3: Renewable fraction [%]; T4: Grid purchase [kWh/year]; T5: Grid sales [kWh/year].
- Financial criteria, (F): F1: Net Present Cost, NPC [€]; F2: Cost of Energy, COE [€]; F3: Initial investment [€]; F4: Simple payback [years].
- Environmental criteria, (E): E1: CO$_2$ emissions [t/year].

Based on the HOMER calculations results, several comparative analyses will be presented. In Figure 5 and Figure 6 the comparatively analysis with respect to NPC and COE is presented. Both wind turbine-based power supply systems are placed in the white area, this means that both are feasible systems. Moreover, the XL wind turbine is the best option with respect to NPC and COE.

Different conclusion can be obtained if CO$_2$ emissions (Figure 7) and grid purchase (Figure 8) criteria are considered: the best option is the XZ wind turbine.
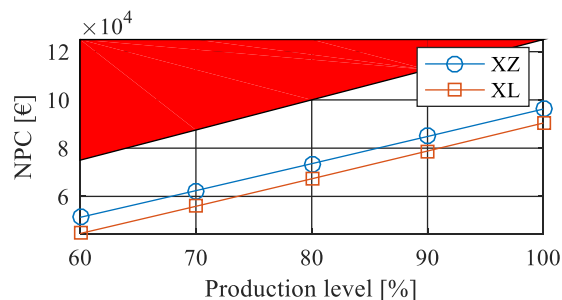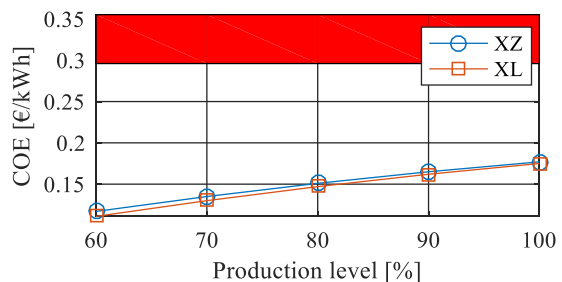

Fig. 5. Net present cost.
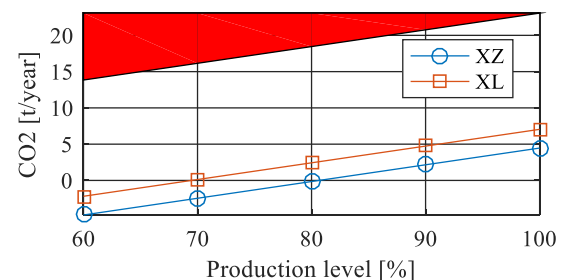

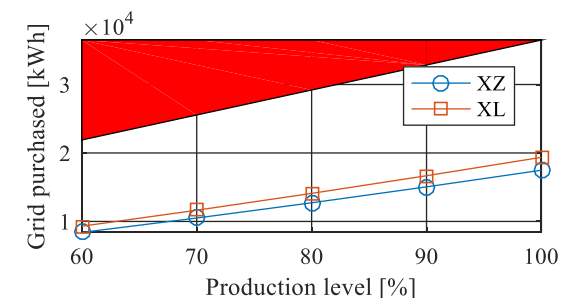**Fig. 6.** Cost of energy.

Fig. 7. CO$_2$ emissions.

Fig. 8. Grid purchase.

The boundary between the white area (feasible systems) and the red area (prohibitive systems) for all figures presented above, represent the grid behaviour in terms of NPC (Figure 5), COE (Figure 6), CO$_2$ emissions (Figure 7), and grid purchase (Figure 8). Both wind turbines define power supply systems which are better than the grid, but, unfortunately, only on these observations cannot decide upon the best option. If we consider the grid sales (Figure 9) and the renewable fraction (Figure 10), the best option is the XZ wind turbine. On the other hand, if we consider the simple payback criteria (Figure 11), the best option is the XL wind turbine, increasing the decision uncertainty.
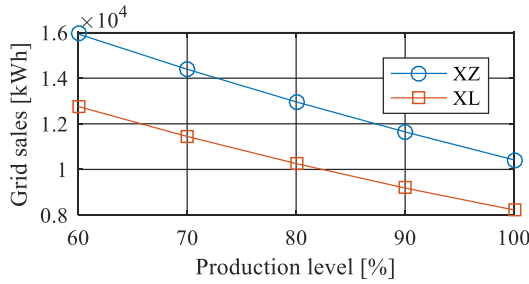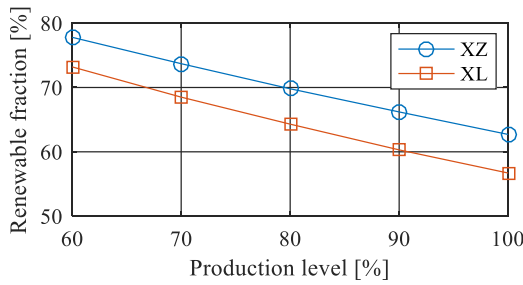
Fig. 9. Grid sales.
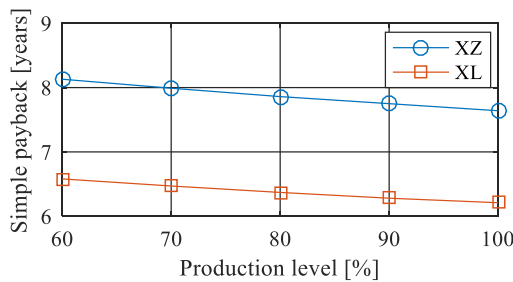

Fig. 10. Renewable fraction.

Fig. 11. Simple payback.

3 TOPSIS method

It is clear that a more complex approach should be used in order to make the decision. In fact, this case study defines a typical multi-dimensional criteria decision-making problem. The main difficulty of this case study is the value of CO_2 emissions criterion, which is negative for both XL and XZ wind turbines for production level value of 60%, is positive for XL wind turbine and negative for XZ wind turbine for production level range of 70÷80%, and finally, is positive for both XL and XZ wind turbines for production level range of 80÷100%, Figure 7. Solving this complex situation will be done using the TOPSIS method [5], which consists in the following main steps:

- Establishing the decision matrix. Let us consider n alternatives A_j, j=1÷n which are evaluated for m criteria C_i, i=1÷m. The decision matrix consists in the performance ratings x_{ij} of i-th criterion with respect to the j-th alternative and is presented in Table 1.

Table 1. Decision matrix.

Decision matrix		Alternatives					
		A_1	A_2	…	A_j	…	A_n
C	C_1	x_{11}	x_{12}	…	x_{1j}	…	x_{1n}
	C_2	x_{21}	x_{22}		x_{2j}		x_{2n}
	⋮	⋮	⋮		⋮		⋮
	C_i	x_{i1}	x_{i2}	…	x_{ij}	…	x_{in}
	⋮	⋮	⋮		⋮		⋮
	C_m	x_{m1}	x_{m2}	…	x_{mj}	…	x_{mn}

- Calculate the normalized decision matrix:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} \qquad (2)$$

- Establishing the weights W_i and computing the normalized weights w_i of the criteria C_i, where i=1÷m and $\sum_{i=1}^{m} w_i = 1$:

$$w_i = \frac{W_i}{\sum_{i=1}^{m} W_i} \qquad (3)$$

- Calculate the weighted normalized decision matrix:

$$v_{ij} = w_i \cdot r_{ij} \qquad (4)$$

- Identify the ideal solution (A^+) and the negative ideal solution (A^-):

$$A^+ = \{v_1^+, v_2^+, ..., v_i^+, ..., v_n^+\} \qquad (5)$$

$$A^- = \{v_1^-, v_2^-, ..., v_i^-, ..., v_n^-\} \qquad (6)$$

where v_i^+ and v_i^- are the best value, respectively the worst value for the i-th criterion among all alternatives.

- Calculate the n-dimensional Euclidean distance between each alternative and the ideal solution:

$$D_j^+ = \sqrt{\sum_{i=1}^{m} \left(v_{ij} - v_i^+\right)^2}, \ j=1÷n \qquad (7)$$

- Calculate the n-dimensional Euclidean distance between each alternative and the negative ideal solution:

$$D_j^- = \sqrt{\sum_{i=1}^{m} \left(v_{ij} - v_i^-\right)^2}, \ j=1÷n \qquad (8)$$

- Calculate the ranking score (the relative closeness to the ideal solution):

$$R_j = \frac{D_j^-}{D_j^+ + D_j^-}, \ j=1÷n \qquad (9)$$

The preference order of the alternatives can be obtained by sorting the ranking scores in descending order, the best alternative having the maximum ranking score.

4 Methodology

The principal steps of applying the TOPSIS method for this case study are:

- Selecting the criteria for finding the most suitable wind turbine. These criteria are T1÷T5, F1÷F4, and E1.
- Selecting the alternatives to be evaluated. There are two alternatives, XZ and XL.
- Score each criterion of each alternative. The raw scores represent the performance ratings (x_{ij}) and will be used for filling the decision matrix. The raw scores come from HOMER simulations. As we mention before, the HOMER project file will be calculated for all five values of production level (60, 70, 80, 90 and 100%), as consequence, five sets of raw scores and five decision matrices will be obtained. The negative values of CO_2 emissions, that have been already noticed, qualitatively, in Figure 7, can be also quantitatively expressed by: -4.766 t/year and -2.185 t/year for XZ and XL wind turbines for 60% production level, Table 2; -2.459 t/year and 0.122 t/year for XZ and XL wind turbines for 70% production level, Table 3; -0.152 t/year and 2.428 t/year for XZ and XL wind turbines for 80% production level, Table 4. For production levels 90% and 100% there are no negative values for CO_2 emissions.

Table 2. Decision matrix for 60% production level.

	Alternatives			
	XZ		XL	
	Raw scores	Normalized scores	Raw scores	Normalized scores
T1	29441	0.7577	25358	0.6526
T2	32.3	0.7452	28.9	0.6668
T3	77.8	0.7283	73.2	0.6852
T4	8396	0.6700	9302	0.7423
T5	15937	0.7806	12760	0.6250
F1	51312	0.7547	44609	0.6561
F2	0.117	0.7255	0.111	0.6883
F3	55905	0.8133	40000	0.5819
F4	8.13	0.7773	6.58	0.6291
E1	-4.766	-0.9090	-2.185	-0.4167

Table 3. Decision matrix for 70% production level.

	Alternatives			
	XZ		XL	
	Raw scores	Normalized scores	Raw scores	Normalized scores
T1	29441	0.7577	25358	0.6526
T2	32.3	0.7452	28.9	0.6668
T3	73.7	0.7325	68.5	0.6808
T4	10499	0.6699	11637	0.7425
T5	14390	0.7826	11445	0.6225
F1	62382	0.7448	55894	0.6673
F2	0.135	0.7203	0.13	0.6936
F3	55905	0.8133	40000	0.5819
F4	7.99	0.7772	6.47	0.6293
E1	-2.459	-0.9988	0.122	0.0496

Table 4. Decision matrix for 80% production level.

	Alternatives			
	XZ		XL	
	Raw scores	Normalized scores	Raw scores	Normalized scores
T1	29441	0.7577	25358	0.6526
T2	32.3	0.7452	28.9	0.6668
T3	69.8	0.7355	64.3	0.6775
T4	12721	0.6699	14099	0.7425
T5	12962	0.7842	10257	0.6205
F1	73562	0.7378	67296	0.6750
F2	0.151	0.7165	0.147	0.6976
F3	55905	0.8133	40000	0.5819
F4	7.96	0.7769	6.37	0.6296
E1	-0.152	-0.0625	2.428	0.9980

- Using formula (2), the raw scores will be normalized, obtaining the normalized scores presented for 60%, 70% and 80% in Tables 2, 3 and 4.
- Weighting the criteria to reflect their relative importance to the decision. Weights ($W_i \in N$) have been obtained by subjective direct assignation on a preference scale within the range 1÷m, where 1 correspond with the least preferred option and m correspond with the most preferred option. Weighting the criteria is made according with the project strategy. For example, one possible strategy can be expressed by: the most preferred is the environmental criterion (E), the least preferred are the financial criteria (F), while the technical criteria are between the environmental and the financial criteria, defining thus the strategy S1-ETF. In this paper eleven strategies will be presented, S1÷S5 based on T, F and E criteria; S6 and S7 based only on T and F criteria; S8 and S9 based only on F and E criteria; S10 and S11 based only on T and E criteria.
- Computing the normalized weights w_i with (3).
- Computing the weighted normalized decision matrix v_{ij} with (4).
- Identifying the ideal solution (A^+) and the negative ideal solution (A^-) with (5) and (6).
- Computing the n-dimensional Euclidean distance between each alternative and the ideal solution D_j^+, as well as between each alternative and the negative ideal solution D_j^- with (7) and (8).
- Computing the ranking score R_j with (9).
- Ranking the alternatives according with the ranking scores.

5 Weighting strategies based on T, F and E criteria

For this case, five weighting strategies have been considered: S1-ETF, S2-TEF, S3-EFT, S4-FET, and S5-FTE, Table 5.

Table 5. Weighting strategies for T, F and E criteria.

Weights		Strategy				
W_i		S1	S2	S3	S4	S5
Criteria	T1	9	10	5	5	6
	T2	8	9	4	4	5
	T3	7	8	3	3	4
	T4	6	7	2	2	3
	T5	5	6	1	1	2
	F1	4	4	9	10	10
	F2	3	3	8	9	9
	F3	2	2	7	8	8
	F4	1	1	6	7	7
	E1	10	5	10	6	1

Starting with the decision matrices for all production levels, using the weighting strategies S1÷S5 and applying the TOPSIS method algorithm the following results have been obtained:

- the comparative analysis of the ranking scores for XZ (Figure 12) and XL (Figure 13) wind turbines with respect to the weighting strategies S1÷S5;
- the comparative analysis of the ranking scores for S1 (Figure 14), S2 (Figure 15), S3 (Figure 16), S4 (Figure 17) and S5 (Figure 18) weighting strategies with respect to the wind turbines XZ and XL.
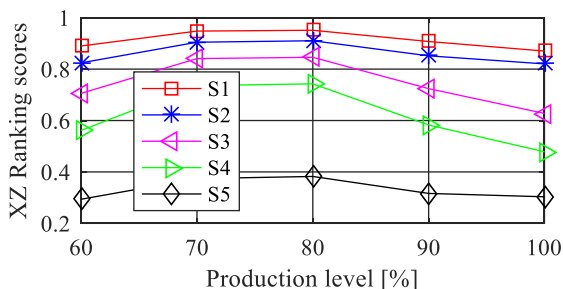

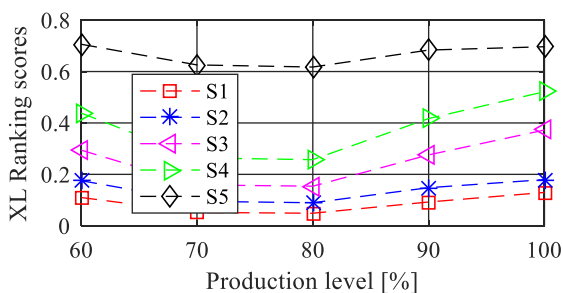**Fig. 12.** Ranking scores for XZ wind turbine.

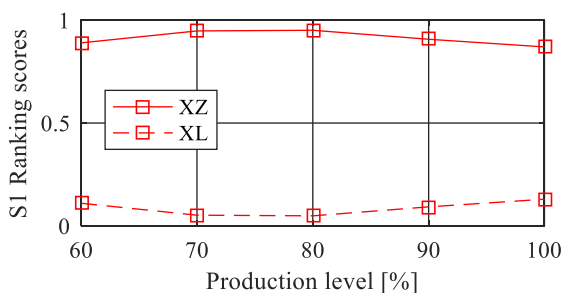**Fig. 13.** Ranking scores for XL wind turbine.

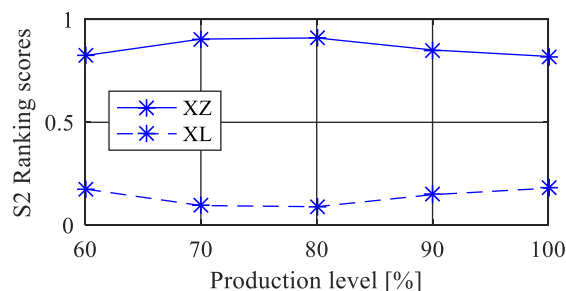**Fig. 14.** Ranking scores for S1 weighting strategy.

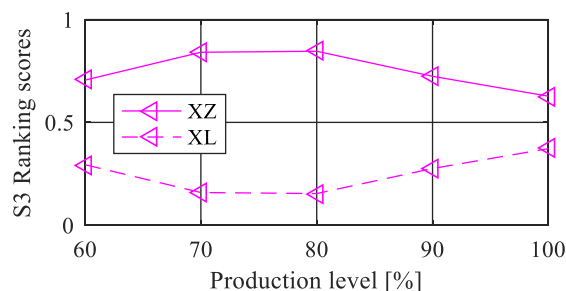**Fig. 15.** Ranking scores for S2 weighting strategy.

Fig. 16. Ranking scores for S3 weighting strategy.

For all weighting strategies the ranking scores will have extreme values for 70% and 80% production levels; however, these extreme values are maximum values for XZ wind turbine (Figure 12), and minimum values for XL wind turbines (figure 13).

For weighting strategies S1 (Figure 14), S2 (Figure 15) and S3 (Figure 16), and for all production levels 60÷100%, the ranking scores of XZ wind turbine are greater than the ranking scores of XL wind turbine.

The difference between ranking scores is maximum for S1 strategy, and decreases to S2 strategy, being at minimum levels for S3 strategy. With respect to the production levels, for the range 70÷80%, the difference between the ranking scores of the alternatives are at maximum levels. Thus, it is clear that for these three strategies (S1, S2 and S3), the decision is that the XZ wind turbine alternative is more suitable than the XL wind turbine alternative, for all production levels, but even more so for inside the range 70÷80%.

A situation less clear can be observed for the S4 weighting strategy (Figure 17). In this case, the ranking scores of XZ wind turbine are greater than the ranking scores of XL wind turbine, but only for production levels between 60% and ≅98%. For production level between 98% and 100%, the ranking scores of XL wind turbine are greater than the ranking scores of XZ wind turbine. For 100% production level the ranking scores are 0.4784 for XZ wind turbine and 0.5215 for XL wind turbine. If the XZ wind turbine will be chosen, even if the ranking score indicates the other alternative, the relative error of this decision will be 8.26%. Thus, for S4 strategy, the decision is that XZ wind turbine alternative is more suitable than the XL wind turbine alternative, without no doubt for production levels inside the range 60÷98%, while for the production level range 98÷100% the relative error of this decision being maximum 8.26%.
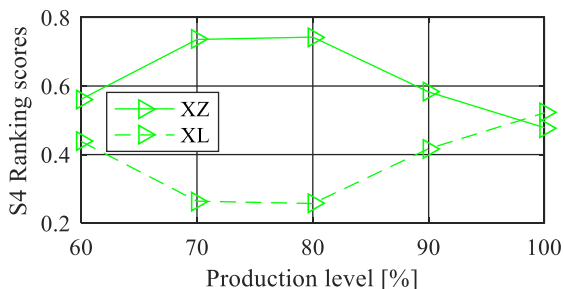
Fig. 17. Ranking scores for S4 weighting strategy.

For S5 weighting strategy (Figure 18), and for all production levels 60÷100%, the ranking scores of XL wind turbine are greater than the ranking scores of XZ wind turbine. With respect to the production levels, for the range 70÷80%, the difference between the ranking scores of the alternatives are at minimum levels. Thus, it is clear that for the S5 strategy, the decision is that the XL wind turbine alternative is more suitable than the XZ wind turbine alternative, for all production levels, but even more so for outside the range 70÷80%.
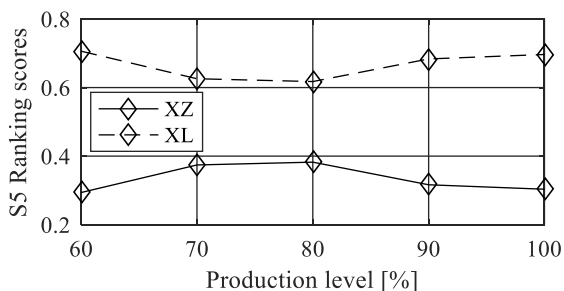

Fig. 18. Ranking scores for S5 weighting strategy.

6 Weighting strategies based only on T and F criteria

The environmental criterion (CO_2 emissions) generates, as has been mentioned before, the negative values situation. What if this criterion will be eliminated from the analysis, and only technical and financial criteria will be used? Analysing the strategy table presented in Table 5, but without E1 criterion, two more strategies can be defined: S6-TF and S7-FT, Table 6.

Table 6. Weighting strategies for T and F criteria.

Weights		Strategy	
W_i		S6	S7
Criteria	T1	9	5
	T2	8	4
	T3	7	3
	T4	6	2
	T5	5	1
	F1	4	9
	F2	3	8
	F3	2	7
	F4	1	6

The comparative analysis of the ranking scores for S6 and S7 weighting strategies with respect to the wind turbines XZ and XL is presented in Figure 19 (S6) and Figure 20 (S7).
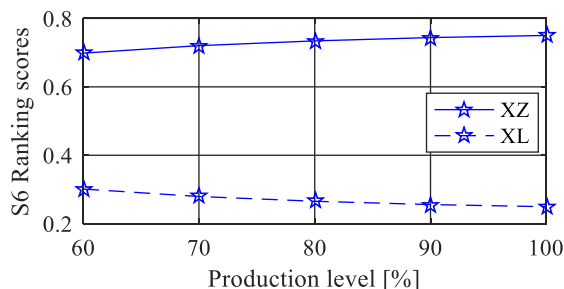

Fig. 19. Ranking scores for S6 weighting strategy.

For weighting strategy S6 (Figure 19), and for all production levels 60÷100%, the ranking scores of XZ wind turbine are greater than the ranking scores of XL wind turbine. The difference between ranking scores increases with production level. Thus, it is clear that for the S6 strategy, the decision is that the XZ wind turbine alternative is more suitable than the XL wind turbine alternative, for all production levels, but even more so for higher production levels.
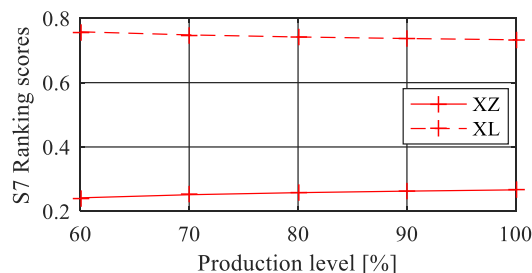

Fig. 20. Ranking scores for S7 weighting strategy.

For weighting strategy S7 (Figure 20), and for all production levels 60÷100%, the ranking scores of XL wind turbine are greater than the ranking scores of XZ wind turbine. The difference between ranking scores decreases with production level. Thus, it is clear that for the S7 strategy, the decision is that the XL wind turbine alternative is more suitable than the XZ wind turbine alternative, for all production levels, but even more so for lower production levels.

7 Weighting strategies based only on F and E criteria

Analysing the strategy table presented in Table 5, but without T criteria, two more strategies can be defined: S8-EF and S9-FE, Table 7.

Table 7. Weighting strategies for F and E criteria.

Weights		Strategy	
W_i		S8	S9
Criteria	F1	4	5
	F2	3	4
	F3	2	3
	F4	1	2
	E1	5	1

The comparative analysis of the ranking scores for S8 and S9 weighting strategies with respect to the wind turbines XZ and XL is presented in Figure 21 (S8) and Figure 22 (S9).
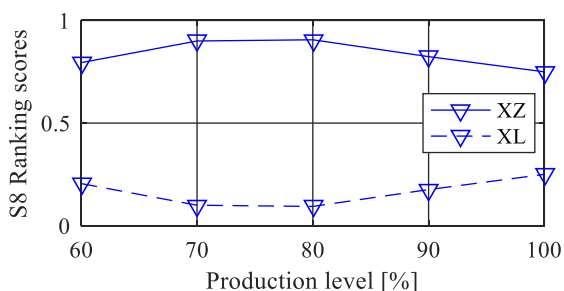

Fig. 21. Ranking scores for S8 weighting strategy.

For weighting strategy S8 (Figure 21), and for all production levels 60÷100%, the ranking scores of XZ wind turbine are greater than the ranking scores of XL wind turbine. Thus, it is clear that for the S8 strategy, the decision is that the XZ wind turbine alternative is more suitable than the XL wind turbine alternative, for all production levels.
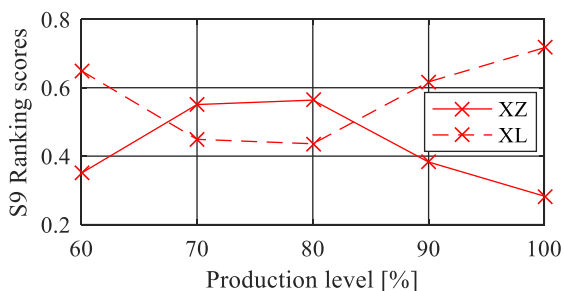

Fig. 22. Ranking scores for S9 weighting strategy.

For weighting strategy S9 (Figure 22), the ranking scores of XZ wind turbine are greater than the ranking scores of XL wind turbine only for production levels in range 67.5÷83.5%. In this case cannot be made any clear decision.

8 Weighting strategies based only on T and E criteria

Analysing the strategy table presented in Table 5, but without F criteria, two more strategies can be defined: S10-TE and S11-ET, Table 8.

Table 8. Weighting strategies for T and E criteria.

Weights W_i		Strategy	
		S10	S11
Criteria	T1	6	5
	T2	5	4
	T3	4	3
	T4	3	2
	T5	2	1
	E1	1	6

For these particular weighting strategies, an interesting result has been obtained: the ranking scores of XZ wind turbine is 1, while the ranking score of the XL wind turbine is 0, for all production levels. This means that the most suitable alternative coincides with the ideal solution, while the other alternative coincides with the negative ideal solution.

9 Conclusions

For a given decision matrix, the weighting strategy of the criteria is extremely important, and may change radically the final decision. Considering T, F and E criteria, it is possible to make a clear decision for all 5 considered weighting strategies: XZ wind turbine for S1, S2, S3 and S4 (for S4 with maximum 8.26% error for 98÷100% production levels), and XL wind turbine for S5.

Considering only T and F criteria, it is also possible to make a clear decision for both S6 and S7 weighting strategies: XZ wind turbine for S6, and XL wind turbine for S7. Considering only E and F criteria it is possible to make a clear decision only for S8 weighting strategy: XZ wind turbine. For S9 weighting strategy it is impossible to make a clear decision. Considering only T and E criteria, it is also possible to decide: XZ wind turbine for both S10, and S11 weighted strategies. Moreover, this is a special case where the XZ wind turbine is identical with the ideal solution, while the other alternative, XL wind turbine, is identical with the negative ideal solution. From all weighting strategies considered in this case study, the XZ wind turbine has been selected for 8 strategies and the XL wind turbine has been selected for 2 strategies.

As regards the negative performance ratings, the key element that allows to use the TOPSIS method is the concept of n-dimensional Euclidean distance between each alternative and the ideal solution, respectively the negative ideal solution.

References

1. L. Sagbansua, F. Balo, Procedia Comput. Sci. **111**, 413 (2017)

2. S. Rehman, S.A. Khan, Int. J. of Adv. Comp. Sci. and Apps. **8,** 128 (2017)

3. A.H.I. Lee, M.C. Hung, H.Y, Kang, W.L. Pearn, Energ. Convers. Manage. **64**, 289 (2012)

4. J.J. Wang, Y.Y. Jing, C.F. Zhang, J.H. Zhao, 2009 Renew. Sust. Energ. *Rev.* **13**, 2263 (2009)

5. G.H. Tzeng, J.J. Huang, *Multiple Attribute Decision Making. Methods and Applications* (CRC Press, 2011)

6. D. Zahariea., C.M. Husaru, D.E. Husaru, IOP Conf.

S.: Mat. Sci. Eng. (to be published)

7. HOMER Energy, *The HOMER Pro microgrid software*, https://www.homerenergy.com/index.html, accessed at 15.05.2018

8. XZERES, 2017, *XZERES 442SR Wind Turbines* http://www.xzeres.com/wind-turbine-products/xzeres-442sr-small-wind-turbine/, accessed at 6.06.2018

9. Bergey, 2017, *The Excel 10 kW Wind Turbine*, http://bergey.com/products/wind-turbines/10kw-bergey-excel, accessed at 2.06.2018

10. NASA Atmospheric Science Data Centre, *Surface Meteorology and Solar Energy Database*, https://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi, accessed at 6.06.2018

11. European Commission, *EUROSTAT, Electricity prices for non-household consumers*, http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do, accessed at 6.06.2018

12. World Bank Group, *State and Trends of Carbon Pricing 2017*, http://documents.worldbank.org/curated/en/468881509601753549/State-and-trends-of-carbon-pricing-2017, accessed at 6.06.2018