Decision Model to Evaluate Projects of Renewable Energy Generation

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Abstract. The goal in this study is bringing up a model to support the decision-making in the problematic of ranking renewable energy generation projects, with solar and wind sources, as parts of a project portfolio. The method considers establishing criteria for ranking the projects, taking their main technical attributes into consideration. The projects evaluation along with the application of the multicriteria method based on Promethee-Roc allowed to accomplish a better and rational selection of projects to be developed and eventually installed.

1 Introduction

Considering the consolidation of wind and solar sources in centralized generation in Brazil, with 20,80 GW (11.45%) and 4.63 GW (2.54%) of participation in the national energetic matrix respectively (ANEEL, 2022), considering the fact that the sources started competing directly in energy auctions in the free market - ACL and in regulated market - ACR, as it is the case of next regulated auction, A-4 2022, authorized by MME by the Portaria Normativa Nº 34//GM/MME from December 22nd of 2021 (ENERGIA, 2022), considering the high investments that these projects require, an appropriate model to guarantee a proper decision concerning ranking projects is relevant. To this kind of problematic, the alternatives should be classified according to parameters with the relative importance amongst them defined. In this case, a multicriteria analysis might be useful for comparing the alternatives in a project portfolio regarding different non-compensatory criteria. Although this type of problematic at deciding has a non-compensatory rationality, the decision-maker should be able to classify by order of importance the criteria that will mark out the project's ranking.

The analysis and ranking of projects parts of a portfolio are a management challenge and they are achieved without the application of a structured method. The article proposes applying a method of comparison pair to the pair among alternatives, exploring a relation of outranking to ranking wind and solar renewable energy projects, based on the Promethee-Roc method (Preference Ranking Method for Enrichment Evaluation - Rank Order Centroid), that applies assigning weights attribution through the ranking of criteria by the degree of importance to the deciding problem.

This article proposes a model for evaluating and ranking renewable energy generation projects, applying a method based on Promethee-Roc. It is a real case regarding this strategic problem in order to support the decision-maker in making the decision and allowing a proper evaluation about which projects should be prioritized for development and future implementation.

The article is structured in four sections: the second section shows a literature review; the third section presents the proposed model and its application; and finally the fourth section with final thoughts.

2 Multicriteria decision

The application of multicriteria decision models to rank renewable energy projects allows to rank, inside a set of projects, which ones should be prioritized to development and future implementation based on criteria defined by the decision-maker.

A multicriteria problem may be defined as being the situation in which a set of actions A and a family of criteria B that the decision-maker wishes to: determine a subset of actions considered by them as being the best from A (selection problematic); place the actions in different categories defined a priori from a set of rules applicable to group A (classification problematic); rank the alternatives of A from best to worst (ranking problematic) (BRANS; VINCKE, 1985).

Multicriteria models of aid to decision are useful to represent real life problems, because they demonstrate the interaction of various contextual aspects. Besides, the multicriteria methods propose a mathematical structure to help the decision-maker evaluate the context, depending on the problematic (MORAIS ET AL., 2015).

Several methods were developed in order to support multicriteria decision problems. Roy (1985) classified these methods as: single criterion of synthesis method and out-rank methods.

The single criterion of synthesis approach guards different points of view in only one function that is after optimized. In the single criterion of synthesis approach, we highlight the methods: Maut (KEENEY; RAIFFA, 1976); Smart (EDWARD; BARRON, 1994), Ahp (SAATY, 1980) and Macbeth (BANA E COSTA; CORTE; VANSNICK, 2005). The outrank approach builds up and explore an outranking relation that represents the decision-maker's preferences. In the outrank approach, we highlight the methods from the family Promethee (BRANS; VINCKE, 1985) and the Electre one (VINCKE, 1992).

The methods may be also classified according to the meaning of constants in the clustering functions. When the constants lead to trade-offs among the criteria, the methods are compensatory, allowing that the disadvantage in some criteria to be balanced by the advantage in others. In such cases, these constants receive the denomination of constants of scale. When the constants only represent measures of relative importance of criteria, the methods are denominated non-compensatory and their denomination is weight. In non-compensatory methods there are no trade-offs among criteria, which means that a bad performance in one of the criteria cannot be compensated by a good performance in another (SILVA et al., 2014).

The selection of the Promethee model as base for the case study was made by the fact that the problem of ranking projects of renewable energy is a multicriteria evaluation and the model proposes dealing with a problematic of ranking based on all the analyzed criteria therefore of non-compensatory rationality. In addition to the explained reasons, there must be added the benefits of the method being easy on the decision-maker's understanding when of the modeling of preference.

2.1 Promethee Family

The methods from the Promethee family are based on two phases: building a relation of outrank adding information among the alternatives and criteria, and the exploration of this relation to support the decision. These methods produce a relation of valued outrank based on concepts that might be interpreted in a physical or economical way by the decision-maker (ALMEIDA, 2013).

The methods from the Promethee family are: Promethee I that considers a partial pre-rank applied in the problematic of ranking; Promethee II that considers a complete pre-rank applied in the problematic of ranking; Promethee III and IV that were developed to deal with decision problems with stochastic components; Promethee V that after establishing a full evaluation among the alternatives based on Promethee II and restrictions are inserted, the selection of a set of alternatives based on the portfolio problematic with entire optimization is then applied; Promethee VI when the decision-maker is not apt or does not want to define precisely the weights for the criteria, stipulating a range of possible values instead of a fixed one for each weight; and finally the Promethee-Roc when the decision-maker is not apt or does not want to define precisely the weights for the criteria but knows how to rank them according to their priorities. In this method the substitute weights are used, Roc, for establishing a complete evaluation amongst the alternatives based on Promethee II (ALMEIDA, 2013).

For this specific case study, we have chosen the Promethee-Roc method giving the problematic of ranking in which the decision-maker does not feel comfortable enough to attribute specific weights for each criterion but feels apt to rank them according to their priorities.

2.2 The Promethee II and Promethee-ROC methods

According to Almeida (2013) the Promethee II method is based on the use of net flows $\phi(a)$ which are obtained in the following way:

$\phi(a) = \phi+(a) - \phi-(a)$

Based on the indicator $\phi(a)$, the alternatives are organized in decreasing order, establishing a complete pre-rank among the alternatives from the following relations:

Relation of Preference: Alternative A is preferred to alternative B if the flow of A is greater than the flow of B;

aPb if $\phi(a) > \phi(b)$;

Relation of Indifference: Alternative A is indifferent to alternative B if the flow of A equals the flow of B;

aIb if $\phi(a) = \phi(b)$;

The starting point for the Promethee method is the matrix of evaluation of alternatives regarding a set of criteria. After that, a function of preference is attributed to each one of the criteria. The function of preference of a criterion describes the way the decision-maker's preference changes with the difference between the levels of performance of two alternatives in this criterion, gj(a) – gj(b), in which gj(a) represents the performance of the alternative year criteria j. The Table 1 presents the functions suggested by the Promethee methods.

The function of preference provides the intensity of preference from one alternative (a) to another (b) regarding a certain criterion (j) is represented by Pj(a,b). The intensity of preference should be calculated for each pair of alternatives, considering all the criteria. For the function usual (Type 1), applied to the case study Pj(a,b) the values 0 or 1 are assumed (SILVA et al., 2014).

Table 1: Function of preference

Type 1: Usual	$gj (a) - gj (b) > 0$	$Pj (a,b) = 1$
	$gj (a) - gj (b) \leq 0$	$Pj (a,b) = 0$
Type 2: U Format	$gj (a) - gj (b) > q$	$Pj (a,b) = 1$
	$gj (a) - gj (b) \leq q$	$Pj (a,b) = 0$
Type 3: V Format	$gj (a) - gj (b) > p$	$Pj (a,b) = 1$
	$gj (a) - gj (b) \leq p$	$Pj (a,b) = [gj (a) - gj (b)]/p$
	$gj (a) - gj (b) \leq 0$	$Pj (a,b) = 0$
Type 4: Levels	$\lvert gj (a) - gj (b)\rvert > p$	$Pj (a,b) = 1$
	$q < \lvert gj (a) - gj (b)\rvert \leq p$	$Pj (a,b) = 1/2$
	$\lvert gj (a) -gj (b)\rvert \leq q$	$Pj (a,b) = 0$
Type 5: Linear	$\lvert gj (a) - gj (b)\rvert > p$	$Pj (a,b) = 1$
	$q < \lvert gj (a) - gj (b)\rvert \leq p$	$Pj (a,b) = [\lvert gj (a) - gj (b)\rvert -q]/(p-q)$
	$\lvert gj (a) - gj (b)\rvert \leq q$	$Pj (a,b) = 0$
Type 6: Gaussian	$gj (a) - gj (b) > 0$	Preference increases according to a normal distribution

The Promethee-Roc method is based on the Promethee II one but applied when the decision-maker isn't capable of or doesn't want to define specific weights for each one of the criteria required for ranking the alternatives. For cases like these we make use of the Roc (Rank Order Centroid) that starting from the criteria definition by order of preference/relative importance to the decision-maker, we can calculate the weights for each one of the criteria according to the equation described below, in which pi is weight of the criterion, m is the quantity of criteria and j the order of preference of the criterion.

$$p_i = \frac{1}{m}\sum_{j=i}^{m}\frac{1}{j}$$

For the elaboration of a model of decision based on Promethee-Roc, the following steps must be overcome (ALMIEDA et al., 2014): Stage 1 - Structuring goals and criteria; Stage 2 - Definition of a set of alternatives; Stage 3 - Establishing the criteria rank; Stage 4 - Calculating the weight of each criterion; Stage 5 - Evaluation of alternatives; Stage 6 - Analysis of sensitivity. The method defined by Almeida will be detailed in the third section when exploring the proposed model.

3 Proposed model and its application

As indicated in the last section, the method for development of the model of support decision is based on the stages settled by Adiel (ALMEIDA et al., 2014) that we will demonstrate and bring up right below.

Stage 1 - Structuring goals and criteria. In this stage the goals and criteria that will be analyzed should be defined.

To the case study, the problem of ranking considers seven wind and solar renewable energy generation projects which should be ranked according to the following criteria: Installed Power; Capacity Factor; Distance to Connection; Transmission Fees; Concession; Construction; Submarket and Connection Availability. For the last criterion a scale from 0 to 10 was defined, in which 0 indicates viability of connection in the long term (more than 5 years), 5 indicates viability of connection in the medium term (from 3 to 5 years) and 10 indicates viability of connection in the short term (up to 3 years).

Stage 2 - Defining the set of alternatives. In this stage the alternatives in analysis are defined in the problematic of ranking.

To this particular case seven renewable projects were analyzed, three by wind source (A, B and C) and four by solar source (D, E, F and G). Below in Table 2 we detail the characteristics of the projects (alternatives).

Table 2: Alternatives

Project	**Description**
Project A	It is an onshore wind project localized in the state of Bahia with total installed power of 1.045 MW and that will count with 190 wind turbines. The connection is proposed in 500 kV with 60 km of transmission lines.
Project B	It's an onshore wind project localized in the state of Bahia with total installed power of 212 MW and that will count with 50 wind turbines. The connection is proposed in 230 kV with 50 km of transmission lines.
Project C	It is an onshore wind project localized in the state of Rio Grande do Norte with total installed power of 120 MW and that will count with 29 wind turbines. The connection is proposed in 230 kV with 60 km of transmission lines.
Project D	It's a photovoltaic solar project localized in the state of Bahia with total installed power of 420 MW with central inverters and trackers with a rotation axis. The connection is proposed in 500 kV with 60 km in transmission lines.
Project E	It's a photovoltaic solar project localized in the state of Ceará with total installed power of 162,14 MW with central inverters and trackers with a rotation axis. The connection is proposed in 230 kV with 10 km of transmission lines.
Project F	It's a photovoltaic solar project localized in the state of Ceará with total installed power of 439,94 MW with central inverters and trackers with a rotation axis. The connection is proposed in 230 kV with 8km of transmission lines.
Project G	It is a photovoltaic solar project localized in the state of Bahia with total installed power of 888 MW with central inverters and trackers with a

	rotation axis. The connection is proposed in 500 kV with 8.2 km of transmission lines.

Stage 3 - Defining the criteria rank. In this stage the criteria will be ranked according to the degree of importance by the decision-maker.

The decision-maker does not feel comfortable in establishing weights for the criteria in evaluation therefore it is required to rank the criteria according to their understanding on their level of importance. See table below:

Table 3: Criteria ranking defined by the decision-maker

Criteria ranking defined by the decision-maker
1 - Capacity factor (%)
2 - Connection Availability
3 - Installed capacity (MW)
4 - Submarket
5 - Distance to connection (kM)
6 - Transmission fees (R$/kW)
7 - Concession (years)
8 - Construction (years)

Stage 4 - Calculating the weight of each criterion. In this stage, considering that the decision-maker was not capable of or did not want to define individual weights for each criterion it is necessary to calculate the weights according to the order of importance defined by the decision-maker. For this activity the equation below is applied for assigning the weights to each criterion.

$$p_1 > p_2 > \cdots > p_i > \cdots p_m$$
$$p_1 = (1 + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{m})/m$$
$$p_2 = (0 + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{m})/m$$
$$p_3 = (0 + 0 + \frac{1}{3} + \cdots + \frac{1}{m})/m$$
$$p_m = (0 + 0 + 0 + \cdots + \frac{1}{m})/m$$

$$\boxed{p_i = \frac{1}{m}\sum_{j=i}^{m}\frac{1}{j}}$$

In which:

pi = weight

m = quantity of criteria

j = order of the criterion

That said, for the particular case the following weights were observed, calculated from the order of preference established by the decision-maker.

Table 4: Weights calculated for each criterion

Criteria	Weights
Installed capacity (MW)	0,152
Capacity factor P50 (%)	0,340
Distance to connection (kM)	0,079
Transmission fees (R$/kW)	0,054
Concession (years)	0,033
Construction (years)	0,016
Submarket	0,111
Connection availability (0 = LT; 5 = MT; 10 = ST)	0,215

Stage 5 - Evaluation of alternatives. In this stage, the alternatives are evaluated pair by pair in each one of the defined criteria.

For each criterion the relation of preference between alternatives was evaluated.

Table 5: Matrix of alternatives and criteria

	Project						
Criteria	A - Wind	B - Wind	C - Wind	D - Solar	E - Solar	F - Solar	G - Solar
Installed capacity (MW)	1.045,00	212,00	120,00	420,00	162,14	439,94	888,00
Capacity factor P50 (%)	50,30%	46,52%	52,24%	27,60%	29,42%	32,66%	31,16%
Distance to connection (kM)	60,00	50,00	60,00	60,00	10,00	8,00	8,20
Transmission fees (R$/kW)	7,59	7,86	7,33	7,59	6,75	6,94	7,80
Concession (years)	20	20	20	20	20	20	20
Construction (years)	3	2	2	2	1,5	2	2,5
Submarket	NE	NE	NE	NE	NE	NE	NE
Connection availability (0 = LT; 5 = MT; 10 = ST)	0	10	5	0	10	10	0

a) Evaluation of alternatives according to the criterion of Total Installed Power (MW)

Table 6: Pair-to-pair evaluation for the criterion Installed Power (MW)

Installed capacity (MW)		A - Wind	B - Wind	C - Wind	D - Solar	E - Solar	F - Solar
		1045,00	212,00	120,00	420,00	162,14	439,94
A - Wind	1045,00		1	1	1	1	1
B - Wind	212,00	0		1	0	1	0
C - Wind	120,00	0	0		0	0	0
D - Solar	420,00	0	1	1		1	0
E - Solar	162,14	0	0	1	0		0
F - Solar	439,94	0	1	1	1	1	
G - Solar	888,00	0	1	1	1	1	1

b) Evaluation of alternatives according to the criterion Capacity factor (%)

Table 7: Pair-to-pair evaluation for the criterion Capacity factor (%)

Capacity factor P50 (%)		A - Wind	B - Wind	C - Wind	D - Solar	E - Solar	F - Solar
		50,30%	46,52%	52,24%	27,60%	29,42%	32,66%
A - Wind	50,30%		1	0	1	1	1
B - Wind	46,52%	0		0	1	1	1
C - Wind	52,24%	1	1		1	1	1
D - Solar	27,60%	0	0	0		0	0
E - Solar	29,42%	0	0	0	1		0
F - Solar	32,66%	0	0	0	1	1	
G - Solar	31,16%	0	0	0	1	1	0

c) Evaluation of alternatives according to the criterion Distance to the Connection Point (km)

Table 8: Pair-to-pair evaluation for the criterion Distance to the Connection (km)

Distance to connection (kM)		A - Wind	B - Wind	C - Wind	D - Solar	E - Solar	F - Solar
		60,00	50,00	60,00	60,00	10,00	8,00
A - Wind	60,00		0	0	0	0	0
B - Wind	50,00	1		1	1	0	0
C - Wind	60,00	0	0		0	0	0
D - Solar	60,00	0	0	0		0	0
E - Solar	10,00	1	1	1	1		0
F - Solar	8,00	1	1	1	1	1	
G - Solar	8,20	1	1	1	1	1	0

d) Evaluation of alternatives according to the criterion Transmission fee (R$/kW)

Table 9: Pair-to-pair evaluation for the criterion Transmission fee (R$/kW)

Transmission fees (R$/kW)		A - Wind	B - Wind	C - Wind	D - Solar	E - Solar	F - Solar
		7,59	7,86	7,33	7,59	6,75	6,94
A - Wind	7,59		1	0	0	0	0
B - Wind	7,86	0		0	0	0	0
C - Wind	7,33	1	1		1	0	0
D - Solar	7,59	0	1	0		0	0
E - Solar	6,75	1	1	1	1		1
F - Solar	6,94	1	1	1	1	0	
G - Solar	7,80	0	1	0	0	0	0

e) Evaluation of alternatives according to the criterion Term of Concession (years)

Table 10: Pair-to-pair evaluation for the criterion Term of Concession (years)

Concession (years)		A - Wind	B - Wind	C - Wind	D - Solar	E - Solar	F - Solar
		20,00	20,00	20,00	20,00	20,00	20,00
A - Wind	20,00		0	0	0	0	0
B - Wind	20,00	0		0	0	0	0
C - Wind	20,00	0	0		0	0	0
D - Solar	20,00	0	0	0		0	0
E - Solar	20,00	0	0	0	0		0
F - Solar	20,00	0	0	0	0	0	
G - Solar	20,00	0	0	0	0	0	0

f) Evaluation of alternatives according to the criterion Period/Deadline of Construction (years)

Table 11: Pair-to-pair evaluation for the criterion Period/Deadline of Construction (years)

Construction (years)		A - Wind	B - Wind	C - Wind	D - Solar	E - Solar	F - Solar
		3,00	2,00	2,00	2,00	1,50	2,00
A - Wind	3,00		0	0	0	0	0
B - Wind	2,00	1		0	0	0	0
C - Wind	2,00	1	0		0	0	0
D - Solar	2,00	1	0	0		0	0
E - Solar	1,50	1	1	1	1		1
F - Solar	2,00	1	0	0	0	0	
G - Solar	2,50	1	0	0	0	0	0

g) Evaluation of alternatives according to the criterion Submarket.

Table 12: Submarket of energy

Submarket		A - Wind	B - Wind	C - Wind	D - Solar	E - Solar	F - Solar
		NE	NE	NE	NE	NE	NE
A - Wind	NE		0	0	0	0	0
B - Wind	NE	0		0	0	0	0
C - Wind	NE	0	0		0	0	0
D - Solar	NE	0	0	0		0	0
E - Solar	NE	0	0	0	0		0
F - Solar	NE	0	0	0	0	0	
G - Solar	NE	0	0	0	0	0	0

h) Evaluation of alternatives according to the criterion of Connection availability

Table 13: Connection availability

Disponibilidad de Conexão		A - Wind	B - Wind	C - Wind	D - Solar	E - Solar	F - Solar
		0,00	10,00	5,00	0,00	10,00	10,00
A - Wind	0		0	0	0	0	0
B - Wind	10	1		1	1	0	0
C - Wind	5	1	0		1	0	0
D - Solar	0	0	0	0		0	0
E - Solar	10	1	0	1	1		0
F - Solar	10	1	0	1	1	0	
G - Solar	0	0	0	0	0	0	0

g) Outrank degree.

Table 14: Outrank degree, calculus of positive, negative and net flow

	A - Wind	B - Wind	C - Wind	D - Solar	E - Solar	F - Solar	G - Solar	∑	ϕ+	ϕ
A - Wind		0,5	0,2	0,5	0,5	0,5	0,5	2,7	0,453	0,158
B - Wind	0,3		0,4	0,6	0,5	0,3	0,6	2,8	0,465	0,154
C - Wind	0,6	0,4		0,6	0,3	0,3	0,6	2,9	0,489	0,155
D - Solar	0,0	0,2	0,2		0,2	0,0	0,1	0,6	0,099	-0,542
E - Solar	0,4	0,1	0,5	0,7		0,1	0,3	2,1	0,348	-0,088
F - Solar	0,4	0,3	0,5	0,8	0,6		0,7	3,3	0,544	0,312
G - Solar	0,1	0,3	0,2	0,6	0,6	0,2		1,9	0,318	-0,149
∑	1,8	1,9	2,0	3,8	2,6	1,4	2,8			
ϕ-	0,30	0,31	0,33	0,64	0,44	0,23	0,47			

h) Complete pre-rank

Table 15: Complete Pre-rank

Rank	Alternative	ϕ
1ª	F	0,312
2ª	A	0,158
3ª	C	0,155
4ª	B	0,154
5ª	E	-0,088
6ª	G	-0,149
7ª	D	-0,542

Stage 6 - Sensitivity analysis. In this stage we evaluate how the results may vary with alterations in the assigned weights.

For this case study, the choice was not to go through a sensitivity analysis.

4 Conclusion

In attention to the defined goal for the research work, the article proposes a multicriteria model to support decision to rank wind and solar renewable energy generation projects applying a Promethee-Roc based method. As result, the projects were ranked the following way: Project F - UFV, Project A - EOL, Project C – EOL, Project B – EOL, Project E – UFV, Project G – UGV e Project D – UFV.

It was observed that the criteria Submarket and Term of Concession have not interfered in the rank given that every project analyzed is found in the Northeast region of Brazil where they consider concessions with a 20-year period of exploration.

The conclusion at last is that the method applied helps the decision-maker in the process of ranking projects in portfolio, allowing the allocation of resources for development and implementation of the projects that in general largely respond to the criteria established by the decision-maker.

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