CHOOSING PHOTOVOLTAIC PANELS USING THE PROMETHEE METHOD

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ABSTRACT
In this article, we study the possibility of using the PROMETHEE method when choosing multi-junction photovoltaic panels. The study performed proves that the PROMETHEE method may be used for selecting technical solutions in case of multi-junction photovoltaic panels, as well as in case of other types of construction installation works. This article fills a void when it comes to choose the technical solutions for construction installation works.

KEYWORDS: *renewable energy, PROMETHEE method, photovoltaic panels.*

JEL CLASSIFICATION: *C61, Q20*

1. INTRODUCTION

In this article, we study the possibility of using the PROMETHEE method when choosing multi-junction photovoltaic panels.
The PROMETHEE (**P**reference **R**anking **O**rganization **Meth**od for **E**nrichment **E**valuation) method is one of methods the most frequently used in order to fundament multicriterial decisions.
The PROMETHEE I method and the PROMETHEE II method were developed by J. P. Brans and they were first presented in 1982, at the "L'INGÉNIERIE de la decizia" conference organized at the Laval University of Canada (Brans, 1982).
Then, the PROMETHEE method was developed in Brans and Vincke's paper in 1985 (Brans & Vincke, 1985), and then in 1986 in a paper published by Brans and collaborators (Brans, et al., 1986).
In time, six variants of the PROMETHEE method were developed, starting with PROMETHEE I and ending with PROMETHEE VI. Also, extensions of the PROMETHEE method were proposed, such as the GAIA method (**G**eometrical **A**nalysis for **I**nteractive **A**id) (Mareschal & Brans, 1988), the sensitivity analysis (Mareschal, 1988) and the group decision-making method (Macharis et al., 1998).
In order to decrease the necessary decision-making time, the method's authors developed several specialized software programs using the PROMETHEE method, namely PROMCALC, DECISION LAB 2000, Visual Promethee and D-Sight.
The PROMETHEE method was applied in various fields of activity, such as the banking system, investments, medicine, chemistry, tourism, etc. (Tomić et al., 2013).

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The study performed proves that the PROMETHEE method may be used for selecting technical solutions in case of multi-junction photovoltaic panels, as well as in case of other types of construction installation works.
This article fills a void when it comes to choose the technical solutions for construction installation works.

2. FORMULATING THE PROBLEM

Six variants of the PROMETHEE method were developed, and the practice currently uses two methods, namely the PROMETHEE I method together with the PROMETHEE II method.

2.1. Stages of the PROMETHEE method

In order to apply the PROMETHEE method, the following five stages must be complied with:
- establishing the elements of the decision-making process;
- applying the PROMETHEE I method;
- applying the PROMETHEE II method;
- performing the sensitivity analysis;
- ranking the actions and choosing the best action (v. fig. 1).

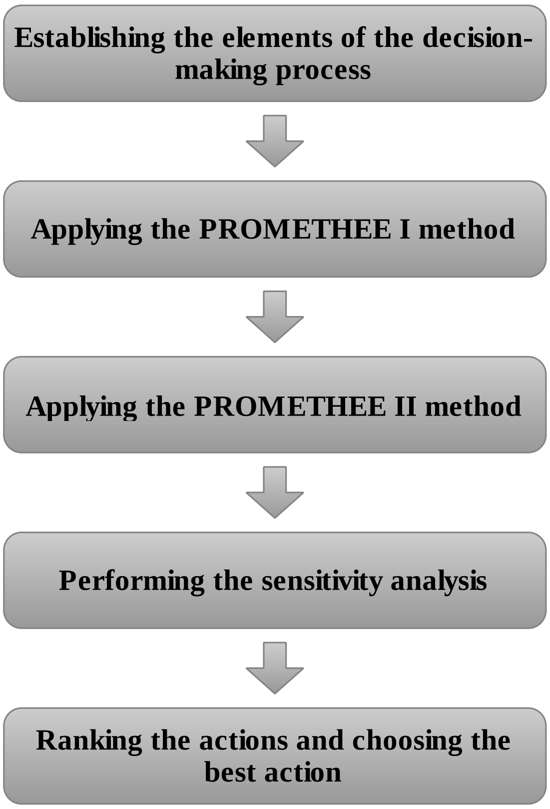

Figure 1. Stages of the PROMETHEE method

2.2 Establishing the elements of the decision-making process

As it is the case with the other multicriterial methods, a set of alternatives A = {a1, a2, ..., am} are to be assessed using a set of criteria C = {c1, c2, ..., cn}.
Further on, one established the performances of the alternatives associated to each criterion, and then each criterion is weighted depending on its importance.

The weights associated to decision-making criteria are positive, therefore wk > 0, and the sum of the weights associated to decision-making criteria must equal 1 (Wikipedia, 2014).

$$\sum_{k=1}^{n} wk = 1 \quad (1)$$

where:
wk is the weight associated to criterion k.
In this paper, we shall not present the methodology for establishing the decision-making criterion weight.
The elements of the decision-making process are synthetically presented in the performance matrix (see table no. 1).

Table 1. Performance matrix

A	**C**				
	$\mathbf{c_1}$	**...**	$\mathbf{c_k}$	**...**	$\mathbf{c_n}$
a_1	c1(a1)	…	ck(a1)	…	cn(a1)
a_2	c1(a2)	…	…	…	…
…	…	…	…	…	…
ai	c1(ai)	…	ck(ai)	…	cn(ai)
aj	c1(aj)	…	ck(aj)	…	cn(aj)
…	…	…	…	…	…
a_m	c1(am)	…	ck(am)	…	cn(am)
w	w1	…	wk	…	wn

2.3 PROMETHEE I method
In the case of the PROMETHEE method, the performances of the possible alternatives must not be necessarily normalized or transformed in a common dimensionless scale (Prejmerean, 2012).
This method uses the preference function pk(ai,aj), which is a function of the “dk” difference between two alternatives for any “k” criterion, for instance dk(ai,aj) = ck(ai) - ck(aj), where ck(ai) and ck(aj) are the values of the two “ai” and “aj” alternatives for the “k” criterion (Euroconsultants, 2011).
The values of the preference function range from 0 to 1, namely 0 ≤ pk(ai, aj) ≤ 1. A value equal to 0 shows no preference, while a value equal to 1 means an uncontestable preference for the best alternative (Mareschal, 2009).
In order to determine the preference function, one uses six criterion-related functions, namely: the usual criterion, the U type criterion, the V type criterion, the level criterion, the linear preference criterion and the Gaussian criterion.
The preference functions used in the case of the PROMETHEE method are transposed as follows (Wikipedia, 2014):
- Usual:

$$pk(dk) = \begin{cases} 0 & if, dk \leq 0 \\ 1 & if, dk > 0 \end{cases} \quad (2)$$

- U-Shape:

$$pk(dk)=\begin{cases}0 & if, |dk|\le qk\\ 1 & if, |dk|>qk\end{cases} \tag{3}$$

- V-Shape:

$$pk(dk)=\begin{cases}\dfrac{|dk|}{pk} & if, |dk|\le pk\\ 1 & if, |dk|>pk\end{cases} \tag{4}$$

- Level:

$$pk(dk)=\begin{cases}0 & if \quad |dk|\le qk\\ 0.5 & if \quad qk<|dk|\le pk\\ 1 & if \quad |dk|>pk\end{cases} \tag{5}$$

- Linear:

$$pk(dk)=\begin{cases}0 & if \quad |dk|\le qk\\ \dfrac{|dk|-qk}{pk-qk} & if \quad qk<|dk|\le pk\\ 1 & if \quad |dk|>pk\end{cases} \tag{6}$$

- Gaussian:

$$pk(dk)=1-e^{-\frac{dk^2}{2sk^2}} \tag{7}$$

where:
q is the indifference limit;
p - preference limit.

The “q” indifference limit and the “p” preference limit are defined depending on the type of criterion chosen for the preference functions (Euroconsultants, 2011).

In practice, one usually currently uses four preference functions, and the field of use of these preference functions is the following:

- the usual type preference function is used in case of qualitative criteria using a scale of up to five levels;
- the level preference function is used in case of qualitative criteria using a scale of more than five levels;
- the V type preference function and the linear function are generally used in case of quantitative criteria.

Further on, one determines the multicriterial preference index, π(ai,aj), which is the weighted average of the pk(ai,aj) preference functions for all the criteria used for defining the outranking flows, as one can see (Euroconsultants, 2011):

$$\pi(ai,aj) = \frac{\sum_{k=1}^{n} wk \bullet pk(ai,aj)}{\sum_{k=1}^{n} wk} \quad (8)$$

where:
π(ai,aj) is the multicriterial preference index;
pk(ai,aj) - preference function (Euroconsultants, 2011).
π (ai,aj) has values ranging from 0 to 1 (Prejmerean, 2012).

Further on, one makes a matrix related to the calculation of the preference flows based on the multicriterial preference index (see table no. 2).

Table 2. Calculation of preference flows

π(ai,aj)	**a1**	**a2**	**…**	**an**	**ϕ+(ai)**
a1	0,00				
a2		0,00			
..			0,00		
an				0,00	
ϕ-(ai)					---
ϕ(ai)					---

Source: from Mareschal, (2012), p. 53

Based on the values of this matrix, one determines the outranking index as well as the outranked index, using the following formulas.

$$\phi^{+}(ai) = \sum_{A} \pi(ai,aj) \quad (9)$$

$$\phi^{-}(ai) = \sum_{A} \pi(aj,ai) \quad (10)$$

where:
Φ+(ai) is the outranking index for “ai” in the A alternative set;
Φ^-(ai) - outranked index for “ai” in the A alternative set.

The positive outranking flow Φ+(ai) shows that an “ai” alternative outranks all the other alternatives, while the negative outranking flow Φ^-(ai) shows that an alternative is outranked by all the other alternatives. Therefore, in the case of the PROMETHEE I method, one obtains a partial ranking based on the positive and negative outranking flows (Euroconsultants, 2011).

The results obtained based on the formulas 9 and 10 shall be interpreted as follows:

- in the case of the outranking index Φ+(ai), the variant bearing the highest flow is on the first place and therefore the actions shall be ranked depending on the decreasing value of the outranking index;
- in the case of the outranked index Φ-(ai), the variant bearing the lowest flow is on the first place and therefore the actions shall be ranked depending on the increasing value of the outranked index (Azzabi, 2010).

It results that an ideal action would bear a positive flow preferably equal to 1 and a negative flow preferably equal to 0 (Wikipedia, 2014).

2.4 PROMETHEE II method

In case of the PROMETHEE II method one practically starts from the results obtained by applying the PROMETHEE I method. The PROMETHEE II method results in a complete ranking, by calculating, for each “ai” alternative of the “A” set of alternatives, the net outranking flow Φ(ai), as follows:

$$\phi(ai) = \phi^{+}(ai) - \phi^{-}(ai) \tag{11}$$

This calculation formula shows the balance between the positive and negative outranking flows. The higher the net flow is, the better that respective alternative is (Euroconsultants, 2011).

The ranking obtained by applying the PROMETHEE II method shall be interpreted as follows:

- the “ai” alternative is preferred over the “aj” alternative, when Φ(ai) > Φ(aj), and
- the “ai” alternative and the “aj” alternative are indifferent, when Φ(ai) = Φ(aj) (Prejmerean, 2012).

2.5 Performing the sensitivity analysis

The sensitivity analysis refers to:

- modifications in the importance weight of the decision-making criteria;
- verification of the stability range of the importance weight of the decision-making criteria (Mareschal, 2012).

2.6 Determining the alternative ranking and choosing the best alternative

After having made the calculations according to the above-presented methodology, one eventually determines the alternative ranking, and then one chooses the best alternative.

3. CASE STUDY

3.1 Determining the elements of the decision-making process

The case study is about choosing multi-junction photovoltaic panels using the PROMETHEE method.

In order to do this, one identified the possible technical solutions (see Table no. 3), the necessary criteria for choosing the photovoltaic panels (see Table no. 4), and then one determined the performances of the technical solutions for each criterion (see Table no. 5.)

Table 3. Multi-junctions cell

A	Multi-junctions cell types	Abbrev.
a1	Triple Junction Solar Cell with eff. 38%	3JC_38%
a2	Triple Junction Solar Cell with eff. 40%	3JC_40%
a3	Triple Junction Solar Cell with eff. 42%	3JC_42%
a4	Triple Junction Solar Cell with eff. 44%	3JC_44%
a5	Four Junction Solar Cell with eff. 45%	4JC_45%

Source: from Badea et al., (2014), p.145

Table 4. Technology assessment criteria

C	Name of criteria	U.M.	Scale	The selected preference function
c1	Efficiency	%	maximized	Usual
c2	Cell dimensions	mm^2	minimized	V-shape
c3	Costs of Production	€/W	minimized	V-shape
c4	Optimal concentrations	x (suns)	maximized	V-shape
c5	Efficient operation capability at concentrations above 1000 x		maximized	V-shape

Source: adapted from Badea et al., (2014), p.145

Table 5. Specific characteristics of MJ Cell

C	Name of criteria	3JC_38%	3JC_40%	3JC_42%	3JC_44%	4JC_45%
c1	Efficiency	38%	40%	42%	44%	45%
c2	Cell dimensions	100	100	100	30,25	6,25
c3	Costs of Production	1,6	1,76	1,92	2,08	2,16
c4	Optimal concentrations	500	500	1000	1000	350
c5	Efficient operation capability at concentrations above 1000 x	no	no	yes	yes	no

Source: from Badea et al., (2014), p.146

4. RESULTS AND DISCUSSIONS

4.1 Results

In this case study, only one decision-making person took the decision, and the weights of the decision-making criteria were determined using the matrix method.

4.1.1 Results obtained using the PROMETHEE I method

By applying the PROMETHEE I method one obtains the outranking index, as well as the outranked index (see table 6 and figure 2).

Table 6. Outranking index and outranked index

Action	Phi+	Phi-
a1	0,088	0,2687
a2	0,074	0,2643
a3	0,3158	0,0665
a4	0,3885	0,0499
a5	0,1151	0,332

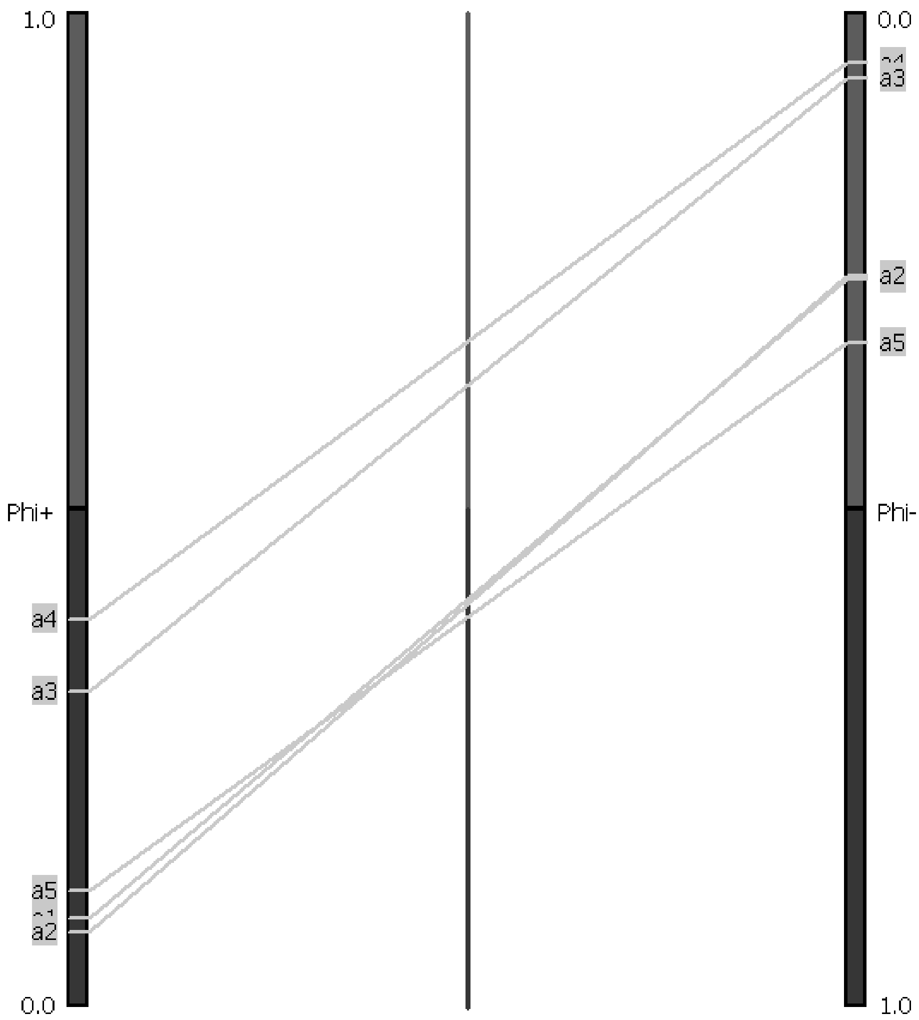

Figure 2. Outranking index and outranked index

4.1.2 Results obtained using the PROMETHEE II method

By applying the PROMETHEE II method one obtains the net outranking flow (see table 7 and figure 3).

Table 7. Net outranking flow

Rank	Action	Phi	Phi+	Phi-
1	a4	0,3386	0,3885	0,0499
2	a3	0,2494	0,3158	0,0665
3	a1	-0,1807	0,088	0,2687
4	a2	-0,1903	0,074	0,2643
5	a5	-0,2169	0,1151	0,332

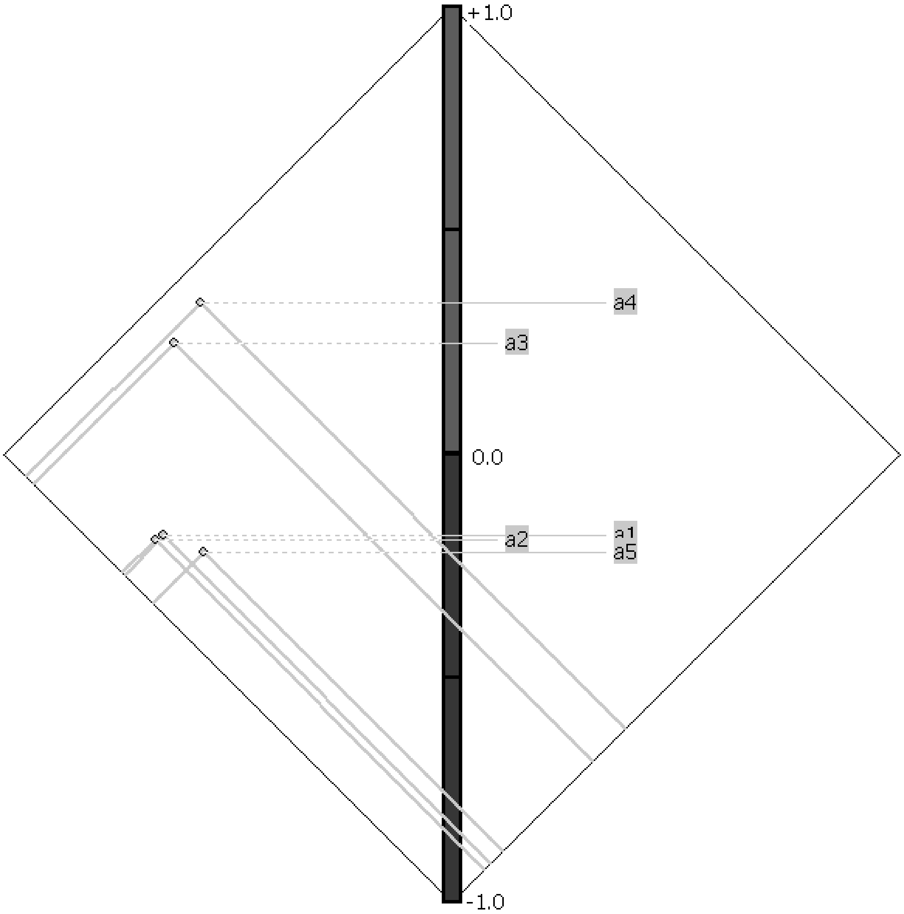

Figure 3. Net outranking flow

4.1.3 Performing the sensitivity analysis

The sensitivity analysis was made in relation with the importance weight of the decision-making criteria, and afterwards one checked the stability range for each criterion. The results are synthetically presented in table no. 8, and for the "c3" criterion we presented the stability range in figure 4, as an example.

Table 8. Stability range

Criterion	Weight granted	Intervalul de stabilitate
	%	%
c1	30	0…45.15
c2	10	1.18…11.56
c3	20	11.52…57.73
c4	20	17.07…100
c5	20	0…100

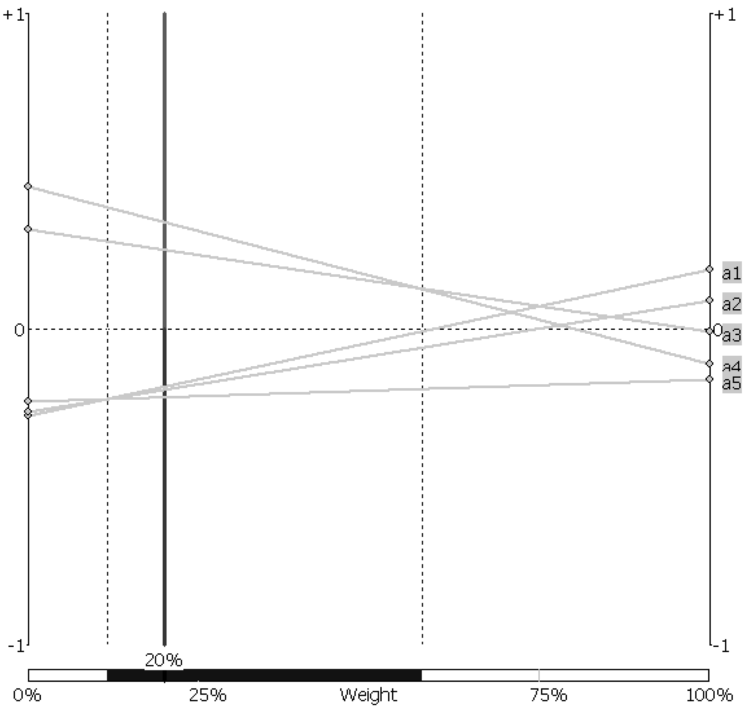

Figure 4. Stability range for the criterion “c3”

4.2 Discussions

As a result of the calculations made, we obtained the following ranking of the alternatives studied: “a4” alternative ranked the first, “a3” alternative ranked the second, “a1” alternative ranked the third, “a2” alternative ranked the fourth and “a5” alternative ranked the fifth.

From the study made, one notices that “a4” alternative ranked the first, and therefore we recommend the practical implementation of this technical solution.

The final ranking may be influenced by:

- the number of analyzed technical solutions (the introduction or exclusion of some technical solutions may influence the final result);
- the number of the decision-making criteria used (the introduction or exclusion of some decision-making criteria may influence the final result);
- the importance weight awarded to the decision-making criteria;
- the type of the preference function chosen in order to determine the preference limit.

4. CONCLUSIONS

From the study made, one notices that “a4” alternative ranked the first, and therefore we recommend the practical implementation of this technical solution.

The study performed proves that the PROMETHEE method may be used for selecting technical solutions in case of multi-junction photovoltaic panels, as well as in case of other types of construction installation works.

This article fills a void when it comes to choose the technical solutions for construction installation works.

At the same time, it results that the PROMETHEE method is based on a utility function, and in this case the multicriterial problem is basically reduced to a single criterion problem for which an optimal solution exists.

The Visual Promethee software greatly reduces the time necessary for substantiating the decisions, and on the other hand it also allows us to make a suggestive presentation of the results obtained.

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