SELECTING THE RIGHT PHOTOVOLTAIC SYSTEM USING THE ENTROPY METHOD

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ABSTRACT
The production of renewable energy using the concentrated solar radiation is a field of high scientific level worldwide, while in Romania the research in this field is only in its early stages. In this paper, in order to select the type of photovoltaic system, we suggested the use of multi-criteria methods, where the utilities are determined based on the Neumann-Morgenstern utility theorem, and the importance coefficients are determined based on the Entropy method. According to the elaborated study, we recommend the implementation into practice of the alternative A3, namely the technical solution involving concentrator photovoltaic panels with dual-axis tracker. The conclusions of this study are useful both for the designers of photovoltaic systems as well as for the potential beneficiaries of photovoltaic systems. Obviously, this method can also be used in case of other investment projects from related fields.

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

JEL CLASSIFICATION: *C61, L74, Q20, Q42*

1. INTRODUCTION

1.1. Context

The more and more efficient photovoltaic systems and the decrease of investment costs during the last years, corroborated with the financial advantages offered by some countries by means of green certificates or "feed in tariff" triggered many investments in photovoltaic energy plants. Despite all these, selecting the best technical solution out of a multitude of photovoltaic systems is a complex process, especially because selecting the right ones depends on many criteria, such as: the efficiency of the photovoltaic system, the value of investment which varies from one photovoltaic system to another, the electric power consumption chronogram, the cost of the land needed for the investment, the difficulty or the impossibility of taking out from agricultural use a large surface of land in order to install the photovoltaic panels, etc.

1.2. The current stage of international research

The production of renewable energy using the concentrated solar radiation is a field of high scientific level worldwide. The technology level in this field is a very advanced one, while research is performed in order to optimize and decrease the investment costs and also the output energy

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costs, together with the decrease of the land areas required for the installation of photovoltaic panels. According to the data provided by National Renewable Energy Laboratory from United States of America (NREL, nd), one can find on the market about 30 different types of photovoltaic cells, having an efficiency between 9.2% - 45,7% and concentration ratio between 1% - 1024% (NREL, 2014), thus noticing an highly increased dynamic of the research results in this field during the last years.

1.3. The current stage of Romanian research

In Romania, the research in this field is still incipient. In the following years, we expect the intensification of the research in this field, due to the important investments in photovoltaic parks in Romania, as well as due to the European and international interest in the matter.
The main individual criterion and multi-criteria methods used for substantiating the decision in the field of fittings for construction are the following: the method of ordinal individual criterion ranks (Giurca, 2009a), the method of ordinal multi-criteria ranks (Giurca, 2009a; Giurca et al., 2013a), the method of real ranks (Giurca, 2009a), the method of the complex quality index (Giurca, 2009a; Giurca, 2009b), the method of the complex quality and economic efficiency index (Giurca, 2009a; Giurca, 2009b), the global performance assessment method (Giurca, 2010; Giurca, 2013b), the utility method (Giurca, 2009a; Naghiu & Giurca, 2015a), maximum score method (Ilina & Lungu, 2000), optimal degree of foreign ownership under uncertainty method (Giurca, 2014a), the relative distance comparison model in relation with the maximum performance (Giurca et al., 2013a), the relative distance comparison model in relation with the average performance (Giurca et al., 2013a), advanced multi criteria analysis (Badea et al., 2015; Naghiu & Giurca, 2015b), comparative analysis method (Giurca, 2009a; Giurca, 2009b; Ilina & Lungu, 2000), the AHP method (Ciocoiu et al., 2013), the Electre method (Aşchilean, 2010; Aşchilean, 2014; Giurca, 2009c; Giurca et al., 2013c; Munteanu, 2003), the Electre-Boldur metod (Cârlan et al., 2010; Naghiu et al., 2015c, *November*), the Onicescu method (Giurca, 2014b), the Promethee method (Giurca et al., 2014c), Topsis method (Giurca et al., 2015, November).

1.4. The purpose described in the article

The purpose of this paper is to present a method of ranking photovoltaic systems, using the multi-criteria methods. We want this method to be used as a research and innovation instrument, useful for selecting the optimal photovoltaic system in the following situations: during the opportunity study phase, during the feasibility study phase and during the phase of elaboration of business plans for the development of new photovoltaic panel plants for producing electrical power.

1.5. The added value of the present article

In order to select the type of photovoltaic system, we suggested the use of the multi-criteria methods, where the utilities shall be determined based on the Neumann-Morgenstern theorem, and the importance coefficients shall be determined using the entropy method.
This article fills a void when it comes to choose the technical solutions for construction installation works.

2. MATERIALS AND METHODS

2.1. Materials

Nowadays, on the market, there are a lot of photovoltaic systems, thus both the designer and the beneficiary found it difficult to choose the photovoltaic systems. These difficulties are caused, on the one hand, by the diverse range of products on the market, and on the other hand by their different technical performances, as well as by the different investment and operation costs.
In this context, in this paper we shall analyze the following alternatives:

- alternative A1 - photovoltaic system with rigid crystalline panels (see figure no. 1). The photovoltaic system with rigid crystalline panels is the system most used for producing electrical power out of solar radiation. These systems convert non-concentrating solar radiation. The efficiency of these systems ranges from 13 % to 16 %;
- alternative A2 - photovoltaic system with portable crystalline panels with dual-axis tracker (see figure no. 2). These systems convert the non-concentrating solar radiation. The efficiency of these systems ranges from 13 % to 16 %;
- alternative A3 - photovoltaic system with concentrating portable panels with dual-axis tracker (see figure no. 3). The photovoltaic system with concentrating portable panels with dual-axis tracker is the most efficient system for producing electrical power out of solar radiation. These systems convert the concentrating solar radiation with a concentration ranging from 300 to 1000 x, the efficiency of these systems ranges from 26 % to 32 %.

Figure 1. Photovoltaic system with rigid crystalline panels
Source: from Remmers et al. (2012, p.11)

Figure 2. Photovoltaic system with portable crystalline panels with dual-axis tracker
Source: from Frontier Associates, LLC (2008, p.3-18)

Figure 3. Photovoltaic system with concentrating portable panels with dual-axis tracker
Source: from Schwartz (2008)

After analyzing the three photovoltaic systems, one notices that these photovoltaic systems have different components, which obviously hinders the analysis of the technical solutions, for details, see table no. 1.

Table 1. Components of the analyzed photovoltaic systems

No.	Alternative name	Components of the photovoltaic system
1	Photovoltaic system with rigid crystalline panels	- rigid system for installing photovoltaic panels; - photovoltaic panels; - power inverter for changing direct current to alternating current; - cables connecting the photovoltaic panels to the inverter.
2	Photovoltaic system with portable crystalline panels with dual-axis tracker	- dual-axis solar tracker on which the photovoltaic panels are installed; - crystalline-based photovoltaic panels; - power inverter for changing direct current to alternating current; - cables connecting the photovoltaic panels to the inverter.
3	Photovoltaic system with concentrating portable panels with dual-axis tracker	- dual-axis solar tracker on which the photovoltaic panels are installed; - concentrating photovoltaic panels with multijunction cells; - power inverter for changing direct current to alternating current; - cables connecting the photovoltaic panels to the inverter.

After analyzing the three photovoltaic systems, one also notices that each of these have advantages and disadvantages, thus the analysis of the various alternatives must be made very carefully. For details see table no. 2.

Table 2. Advantages and disadvantages of analyzed photovoltaic systems

No.	Alternative name	Advantages	Disadvantages
1	Photovoltaic system with rigid crystalline panels	- small investment cost as compared to other systems; - system's simplicity; - possibility of converting global solar radiation, not only direct solar radiation.	- small efficiency of photovoltaic panels, which involves the use of a large surface of land; - rigid position of the photovoltaic panels, which involves the impossibility of converting solar radiation when the solar radiation is under a certain incidence angle (for instance at sunrise or at sunset).
2	Photovoltaic system with portable crystalline panels with dual-axis tracker	- possibility of converting global solar radiation, not only direct solar radiation; - the land on which the panels are installed is not fully occupied, because the distance between two systems is relatively a large one, in order to prevent shading; - 30 % more efficient than rigid photovoltaic systems due to the fact that the solar radiation is maintained perpendicular on the photovoltaic panels helped by the dual-axis tracker which makes it possible to convert solar radiation during the entire time while the sun is shining.	- small efficiency of photovoltaic panels, which means that more systems are needed to produce the same quantity of energy and a larger surface of land is needed as compared to the more efficient systems; - bigger investment costs than in case of rigid crystalline-based systems.
3	Photovoltaic system with concentrating portable panels with dual-axis tracker	- the land on which the panels are installed is not fully occupied, because the distance between two systems is relatively a large one, in order to prevent shading; - more efficient than rigid photovoltaic systems due to the fact that the solar radiation is maintained perpendicular on the photovoltaic panels helped by the dual-axis tracker which makes it possible to convert solar radiation during the entire time while the sun is shining; - more efficient in terms of conversion than any other photovoltaic system, which means that one needs a smaller surface of land.	- impossibility of converting global solar radiation, only direct solar radiation can be converted; - bigger investment costs than in case of rigid or portable crystalline-based systems.

Considering that the various photovoltaic systems have different components, considering that they have a series of advantages and disadvantages, and considering that they have different investment and operation costs, in practice both designers and beneficiaries encounter problems when it comes to select photovoltaic systems.
In this context, when selecting photovoltaic systems, we propose:
- maximizing the yearly period for supplying electrical power, criterion C1;
- minimizing the investment cost, criterion C2;
- minimizing the specific surface of the photovoltaic panels, criterion C3;
- minimizing the surface of land dislocated due to the disposition of the photovoltaic panels, criterion C4;
- maximizing the efficiency of the photovoltaic system, criterion C5.

2.2. Methods

In this paper, in order to select the type of photovoltaic system, we suggested the use of multi-criteria methods, where the utilities are determined based on the Neumann-Morgenstern utility theorem, and the importance coefficients are determined based on the Entropy method.
For instance, the Entropy method may be used in various fields of activity, such as the field of public procurement of electrical works and systems (Dzițac et al., 2009), in the field of heat networks maintenance (Cârlan et al., 2010) and in the field of water management (Mărăcineanu et al., 2007).
In our opinion, in order to apply the Entropy method in this case study, one must take 15 steps, as follows:
Step 1: Determining the purpose. At this stage, one must identify the problem that must be practically solved or to determine the purpose.
Step 2: Establishing the decision-making variants. In this stage, the set of alternatives that can be applied shall be identified, while the data shall be written in the alternatives matrix A = [Ai]. Where i = 1...n, represents the number of alternatives.
Step 3: Establishing the decision-making criteria. Here we shall identify the criteria (objectives) that shall be used for the selection of the alternatives, while the data shall be written in the decision criteria matrix C = [Cj]. Where j = 1...m, represents the number of criteria.
Step 4: Filling in the performance matrix, where the performance of the alternatives shall be identified for each criterion, and the data shall be written in the performance matrix P = [Pij].
Step 5: Calculating the utilities and filling in the utility matrix. The calculation of utilities shall be made based on the performance of alternatives while using the method created by von Neumann and O. Morgenstern in 1947. The usability concept measures the importance given by the decision maker to a certain decision making variant out of a multitude of variants (Ogarca, 2007).
One shall estimate the utility for each criterion alone or for the entire decision table, thus obtaining the multi- criterion utility matrix U = [Uij] (Dobre, 2002).
Depending on the nature of the criteria, the utilities will be calculated according to the following formulas (Petca, nd):
Maximizing criteria:

$$uij = \frac{aij - a\min j}{a\max j - a\min j} \tag{1}$$

Minimizing criteria:

$$uij = \frac{a\max j - aij}{a\max j - a\min j} \tag{2}$$

where:
uij represents the usability of the i variant according to the j criterion;
amax j - the maximum performance obtained by the analyzed variants, according to the j criterion;
amin j - the minimum performance obtained by the analyzed variants, according to the j criterion;
aij - the performance obtained by the i variant according to the j criterion.
One utility corresponds to each consequence.
Step 6: Determining the weight of performance assessment criteria. Considering that the various decision-making criteria used for selecting the alternatives are not equally important, in practice one must determine the importance weight corresponding to various decision-making criteria.
The importance weight of the decision making criteria shall be established using the matrix method (Naghiu & Giurca, 2015a).
One shall elaborate a matrix containing the decision making criteria on the row as well as on the column, and the matrix elements shall be established as follows:
- value 0 if the i criterion is less important than the j criterion;
- value 0.5 if the i criterion is just as important as the j criterion;
- value 1 if the i criterion is more important than the j criterion;
- value 1 on the matrix diagonal.
Afterwards, one calculates, on each line, the sum of values corresponding to each criterion, and the results shall be recorded in the matrix of importance coefficients K = [Kj]. Where j = 1...m, represents the number of criteria.
Step 7: Normalizing the importance coefficients (Kj*). In order to normalize the importance coefficients one shall use the following formula:

$$Kj^* = \frac{Kj}{\sum_{j=1}^{m} Kj} \quad (3)$$

where:
Kj represents the importance coefficients associated to the decision-making criteria;
j = 1...m;
Kj* - the normalized coefficients of performance.
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).

$$\sum_{j=1}^{m} Kj^* = 1 \quad (4)$$

Step 8: Normalizing the utilities. In order to normalize the utilities, one shall use formula no. 5 (Cârlan et al., 2010).

$$Uij^* = \frac{Uij}{\sum_{j=1}^{m} Uij} \quad (5)$$

Step 9: Shannon (hj) entropy for each criterion is calculated based on the normalized utilities and using formula no. 6 (Cârlan et al., 2010; Dzițac et al., 2009; Mărăcineanu et al., 2007):

$$hj = \frac{-1}{\ln(m)} \cdot \sum_{i=1}^{n} Uji * \cdot \ln(Uji*) \qquad (6)$$

where:
hj Є [0,1].
Step 10: The degree of diversification is calculated according to formula no. 7 (Cârlan et al., 2010; Dzițac et al., 2009; Mărăcineanu et al., 2007):

$$dj = 1 - hj \qquad (7)$$

Step 11: The entropy coefficients are calculated based on formula no. 8 (Cârlan et al., 2010; Dzițac et al., 2009; Mărăcineanu et al., 2007):

$$pj = \frac{dj}{\sum_{j=1}^{n} dj} \qquad (8)$$

Step 12: The importance coefficients (Kj^o) are calculated in relation with the entropy coefficients and in relation with the normalized weight coefficients, using, for this, formula no. 9 (Cârlan et al., 2010; Dzițac et al., 2009; Mărăcineanu et al., 2007):

$$Kj^\circ = \frac{Kj * \cdot pj}{\sum_{j=1}^{n} Kj * \cdot pj} \qquad (9)$$

The sum of importance coefficients (Kj^o) must fulfill the following condition:

$$\sum_{j=1}^{m} Kj^\circ = 1 \qquad (10)$$

Step 13: Determining the utilities using the entropy method. The utilities corresponding to the alternatives for each criterion are determined as a product between the corresponding utility and the importance coefficient (Kj^o) corresponding to that specific criterion. And the utility corresponding to an alternative shall result in a sum of the products between the utilities corresponding to that alternative and the importance coefficients (Kj^o), using, for this, formula no. 11 (Mărăcineanu et al., 2007).

$$Ui = \sum_{i=1}^{n} Uij \cdot Kj^\circ \qquad (11)$$

Where i = 1...n.
Step 14: Determining the ranking of alternatives. The optimal alternative is the one for which the sum of the products between the utilities and the importance coefficients is the maximum one, namely (Cârlan et al., 2010):

$$Aopt = \max \sum_{i=1}^{n} Uij \cdot Kj° \tag{12}$$

Step 15: Selecting the optimal alternative. Obviously, the first place is occupied by the alternative for which the sum of the products between the utilities and the importance coefficients takes the biggest value, and the other alternatives shall classify on the following places, in descending order, depending on the values they obtained.

3. CASE STUDY

We propose a case study on how to select the photovoltaic systems, starting from the alternatives and the decision-making criteria identified at chapter 2.1.
Step 1: Determining the purpose. At this stage, one must identify the problem that must be practically solved or to determine the purpose. The purpose of this paper is to present a method of ranking photovoltaic systems, using the multi-criteria methods.
Step 2: Elaborating the alternative matrix. For this case study the alternatives were identified in chapter 2.1 and they are synthetically presented in table no. 3.

Table 3. The set of alternatives

No.	Alternative's symbol	Alternative name
1	A1	Photovoltaic system with rigid crystalline panels
2	A2	Photovoltaic system with portable crystalline panels with dual-axis tracker
3	A3	Photovoltaic system with concentrating portable panels with dual-axis tracker

Source: from Badea et al., (2015), p.222

Step 3: Elaborating the criteria matrix. For this case study the criteria were identified in chapter 2.1 and they are synthetically presented in table no. 4.

Table 4. The set of decision criteria

No.	Criterion's symbol	Name of criterion	M.U.	Nature
1	C1	Yearly duration of supplying electrical power	hours	maximizing
2	C2	Investment value	€/MWh	minimizing
3	C3	Surface of photovoltaic panels	m^2/kWh	minimizing
4	C4	Surface of land dislocated by the disposition of the photovoltaic panels	m^2/kWh	minimizing
5	C5	Efficiency of the photovoltaic system	%	maximizing

Source: from Badea et al., (2015), p.223

4. RESULTS AND DISCUSSIONS

4.1. Results

Step 4: Elaborating the performance matrix. One identified the performances corresponding to each alternative and for each decision-making criterion, and the results are presented in table no. 5. The performances of the photovoltaic systems were taken over from the scholarly literature.

Table 5. Consequence matrix

No.	Alternative's symbol	Criterion's symbol				
		C1	C2	C3	C4	C5
1	A1	1700	1100	7.14	11.71	14 %
2	A2	2210	1300	7.14	2.93	14 %
3	A3	2210	1700	3.13	3.13	32 %

Source: from Badea et al., (2015), p.223

Step 5: Calculating utilities and filling in the utility matrix. The utilities were determined based on the method elaborated by the researchers J. von Neumann and O. Morgenstern, namely by applying the formulas no. 1 and no. 2, and eventually the results were presented in the following table.

Table 6. Matrix of alternative utilities in relation with each criterion, determined based on the Newman-Morgenstern method

No.	Alternative's symbol	Criterion's symbol				
		C1	C2	C3	C4	C5
1	A1	0.000	1.000	0.000	0.000	0.000
2	A2	1.000	0.667	0.000	1.000	0.000
3	A3	1.000	0.000	1.000	0.977	1.000

Step 6: The weight of the performance assessment criteria was determined using the matrix method, and the results were presented in the following table.

Table 7. Matrix of the importance coefficients corresponding to the decision-making criteria

No.	Criterion's symbol	C1	C2	C3	C4	C5	Total
1	C1	0.5	0.5	0.5	0.5	0.5	2.5
2	C2	0.5	0.5	1	0.5	0.5	3
3	C3	0.5	0	0.5	0.5	0.5	2
4	C4	0.5	0.5	0.5	0.5	0.5	2.5
5	C5	0.5	0.5	0.5	0.5	0.5	2.5

Step 7: The importance coefficients were normalized based on formula 3, and the result was presented in the following table.

Table 8. Matrix of the normalized importance coefficients

	Criterion's symbol					Total
	C1	C2	C3	C4	C5	
Kj	2.50	3.00	2.00	2.50	2.50	12.50
Kj*	0.20	0.24	0.16	0.20	0.20	1.00

Step 8: The utilities were normalized based on formula 4, and the results were presented in the following table.

Table 9. Matrix of the normalized utilities

No.	Alternative's symbol	Criterion's symbol					Total	Rank
		C1	C2	C3	C4	C5		
1	A1	0.000	0.600	0.000	0.000	0.000	0.600	3
2	A2	0.500	0.400	0.000	0.506	0.000	1.406	2

3	A3	0.500	0.000	1.000	0.494	1.000	2.994	1
4	Total	1.000	1.000	1.000	1.000	1.000		

Steps 9-12: Their final purpose is to calculate the importance coefficients (Kj^o). The importance coefficients (Kj^o) were calculated based on formulas no. 6-10, and the results were presented in table no. 10.

Table 10. Matrix of importance coefficients (Kj^o), determined by the entropy method

	Criterion's symbol					**Total**
	C1	**C2**	**C3**	**C4**	**C5**	
hj	0.50000	0.48548	0.00000	0.49995	0.00000	
dj	0.5000	0.5145	1.0000	0.5000	1.0000	3.5146
pj	0.142	0.146	0.285	0.142	0.285	1.0000
Kj*	0.200	0.240	0.160	0.200	0.200	1.0000
Kj* x pj	0.028	0.035	0.046	0.028	0.057	0.1945
Kj^o	0.146	0.181	0.234	0.146	0.293	1.0000

Step 13: Determining the utilities using the entropy method. The utilities corresponding to the alternatives for each criterion were determined as a product between the corresponding utility and the importance coefficient (Kj^o) corresponding to that specific criterion. The calculation was made based on formula 11, and the results were presented in table 11.

Table 11. Matrix of utilities weighted with the importance coefficients (Kj^o), determined based on the entropy method

Alternative's symbol	**Criterion's symbol**				
	C1	**C2**	**C3**	**C4**	**C5**
A1	0.000	0.181	0.000	0.000	0.000
A2	0.146	0.120	0.000	0.146	0.000
A3	0.146	0.000	0.234	0.143	0.293
Kj^o	0.146	0.181	0.234	0.146	0.293

Step 14: The ranking of alternatives was determined based on the information presented in table no. 11, and the result is presented in table no. 12. It is obvious that the first place shall be occupied by the alternative for which the sum of the products between the utilities and the importance coefficients (Kj^o) has the maximal value (see formula 12).

Table 12. Ranking of alternatives in case of the entropy method

Alternative's symbol	**Alternative name**	**Total**	**Rank**
A1	Photovoltaic system with rigid crystalline panels	0.181	3
A2	Photovoltaic system with portable crystalline panels with dual-axis tracker	0.413	2
A3	Photovoltaic system with concentrating portable panels with dual-axis tracker	0.816	1

4.2. Discussions

Analyzing the results and the classification presented in table no. 12, one notices that:

- the alternative A3 ranked the first, that is the technical solution with concentrating photovoltaic panels with dual-axis tracker;

- the alternative A2 ranked the second, that is the technical solution with crystalline photovoltaic panels with dual-axis tracker;
- the alternative A1 ranked the third, that is the technical solution with rigid crystalline photovoltaic panels.

According to the simulations made by the authors by applying the Electre-Boldur method, as well as the Advance Multi-Criteria Analysis, we obtained the same classification of alternatives as in the case of the Entropy method.

Step 15: Selecting the optimal alternative. Based on the conclusions presented above, we recommend the practical implementation of the alternative A3, namely the technical solution with concentrating photovoltaic panels with dual-axis tracker.

5. CONCLUSIONS

To conclude, we recommend the practical implementation of the alternative A3, namely the technical solution with concentrating photovoltaic panels with dual-axis tracker.

The conclusions of this study are useful both for the designers of photovoltaic systems as well as for the potential beneficiaries of photovoltaic systems.

Obviously, this method can also be used in case of other investment projects from related fields.

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

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