Evaluatıon Of The Solar Panels In Terms Of Energy Effıcıency

Lutfu Sagbansua [1,1], Figen Balo [2]

[1, 2] *Department of Industrial Engineering, Firat University, Turkey*

Abstract-*Because of the restricted amount of fossil sources and a rise of energy need in the world, there are a lot of interest on sustainable energy resources recently. Both the restricted amount of fossil sources and their negative impacts on the environment rise the requirement for the most frequently used sustainable energy resources such as wind and solar alternatives. Photovoltaic power generation has been one of the fastest growing resources of sustainable technology on the market today. The most significant decision in the photovoltaic power system design is the most performance photovoltaic panel selection due to the high price of these panels.*

In this paper, the AHP framework was performed to choose the best performing 310W photovoltaic panel for a photovoltaic power system design. Seven different photovoltaic panel brands were analyzed based on experts' opinions on five groups of characteristics of these panels. Photovoltaic panel data used is obtained from the panel manufacturers worldwide.

Index Terms-*Photovoltaic panel, Multi-criteria, decision making, AHP, Renewable energy, solar, sustainability*.

List of symbols and abbreviations: AHP, Analytical Hierarchical Process; PROMETHEE, The Preference Ranking Organization Method for Enrichment Evaluation; ELECTRE (Elemination and Choice Translating Reality English); ANP, Analytic Network Process; TOPSIS,Technique for Order of Preference by Similarity to Ideal Solution; ANP, Fuzzy Analytic Network Process; DEMATEL, Decision Making Trial and Evaluation Laboratory.

[1] Corresponding author.
Tel: +90 0424 2370000/5646; Fax: +90 424 2370000

1. Introduction

Researches display that the world will be interdependent on fossil sources for energy production for at least the next 20 years. Using renewable forms of energy such as solar, wind, geothermal and biofuels can also make an important contribution to minimize greenhouse gas emissions and fossil-based energy usage [1]. Cost range according to sustainable energy sources is shown in Fig. 1 [2].

Energy Source	Cost Range	Likliest Cost
Wave Power	\$257 – \$508	\$380
Solar, crystalline silicon panels	\$215 – \$420	\$285
Solar, thin-film panels	\$160 – \$285	\$215
Wind, offshore	\$132 – \$245	\$167
Biomass	\$71 – \$213	\$104
Wind, onshore	\$68 – \$116	\$88
Landfill Gas	\$44 – \$88	\$72
Geothermal	\$53 – \$84	\$62
Natural Gas	\$53 – \$63	\$58
Coal	\$53 – \$59	\$56

Fig. 1. Cost range according to sustainable energy source

Photovoltaic energy is one of the sustainable energy resources that is environmentally friendly and inexhaustible. The sun is the most potent resource of energy in space. Photovoltaic energy usage was raised along with rising energy requirements and increasing fuel prices. [3]. Fig. 2 shows projected global cumulative capacity in MW and cumulative photovoltaic capacity by region in 2015 [4].

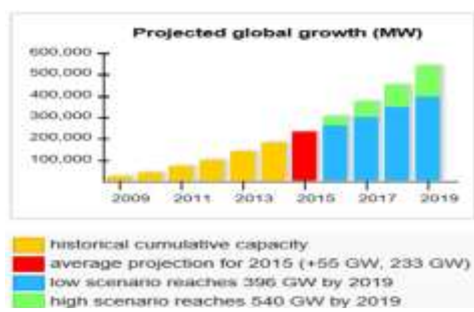
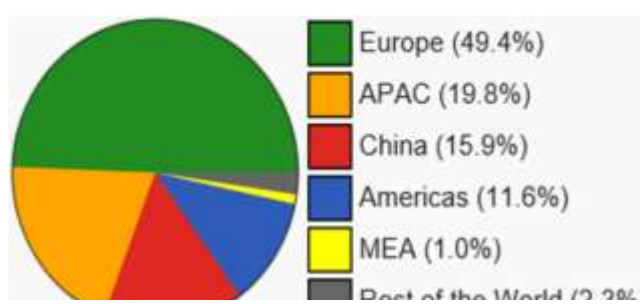


Fig. 2. a- Projected global cumulative capacity in MW



(b)

Fig. 2. b- Cumulative photovoltaic capacity by region in 2015

By a solar impact, photovoltaic panels operate through converting sun's ray into electricity. Without battery back-up, one common design of a grid-connected AC photovoltaic system is displayed in Fig. 3 [5].

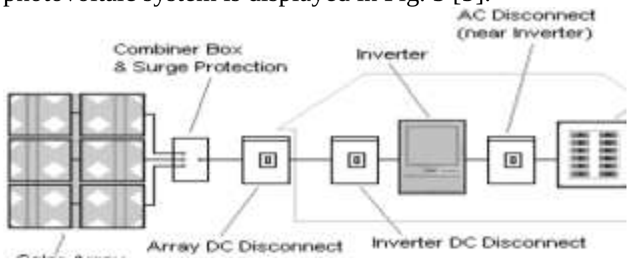


Fig. 3. Without battery back-up, one common design of a grid-connected AC photovoltaic system

The products with lower price and higher efficiency are continuously being developed. The performance of the common products varies from 12% to 18%, depending on the rising generation expenses [6]. The materials of photovoltaic panels can be classified into the following types: Amorphous Silicon, Polycrystalline Silicon, Mono Crystal Silicon, CdS, InP, CuInse, CdTe, CuInGaSe, GaAs. In recent years, photovoltaic panel materials' global market share is shown in Fig. 4 [7].

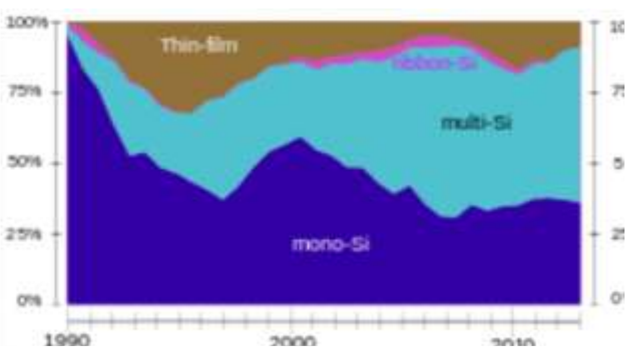


Fig. 4. Photovoltaic panel materials' global market share.

Photovoltaic panel efficiency is extremely dependent on the existence sun's ray. The greater the sun's ray received by the photovoltaic panel surface, the larger the electric energy can be produced. Nonetheless, the rise in sun rays will lead to a rise in the temperature of the photovoltaic panel, which results in a decrease in efficiency. Among all equipment used, photovoltaic panels are one of the highest cost one due to their installation and manufacturing costs. There are numerous photovoltaic panel brands worldwide. The efficiency of a photovoltaic panel can be indicated by various parameters given on the datasheet of photovoltaic panel [8]. For this reason, the best performing photovoltaic panel selection is one of the most significant decisions in the photovoltaic power system design.

Analytical Hierarchical Process is a multi-criteria methodology in the event of determining the relative weights of various parameters involved in decision making. For this reason, analytical hierarchical process is one of the most powerful and popular methods for efficient decision making used in advisable project design. It is a multi-criteria decision making approach that facilitates complex, bad-structured problems by working-out the decision elements in a hierarchical structure [9].

A number of studies have investigated the multi-criteria assessment of devices related to renewable energy. Cavallaro performed an outranking approach to research a choice of output procedures of thin-film photovoltaic panel industry. The multi-criteria decision making method provided a scientific-technical decision assistance apparatus that is able to demonstrate its selections sustained and clearly in the renewable energy industry [10]. By Chen and Yang (2014), the TOPSIS and AHP for multi-criterion decision making method are utilized to research firm-level data, obtained from the photovoltaic equipment companies in the Crystalline Silicon photovoltaic panel sector [11]. Naghiu et al. (2016) analyzed the choice of the optimum solution concerning the concentration ratio of the solar panels with Electre-Boldur Method [12]. Zeyuan (2013) compared different kinds of solar cell and analyzed with TOPSIS [13]. In Algeria, Guenounou et al. (2016) compared the output of photovoltaic panels of various firms during a year of experiment under natural environmental conditions. Four kinds of different photovoltaic panels [polycrystalline silicon (Poli-Si), amorphous silicon (a-Si), monocrystalline silicon (M-Si), and micro morph silicon (l-Si)] are examined by them [13]. A hybrid multi criteria analysis based on the fuzzy PROMETHEE, fuzzy ANP, and fuzzy DEMATEL, used to select the best alternative among the photovoltaic panel, gas engine, gas turbine, fuel cell, and diesel engine by Khorasaninejad et al. [14]. Amin et al. developed area study of different PV panels on their performance [15].

In this paper, AHP methodology is used to select the best 310W photovoltaic panel for the photovoltaic power system design. Literature review and expert opinions have been used to reach at qualitative and quantitative evaluations. The comparative assessment of diverse photovoltaic panel brands is implemented. Each of the panel brands is compared based on five different main criteria (mechanic, electrical, customer, financial and environment). Within these five main criteria, many sub-criteria are determined; similarly, sub-options are noted for each of the solar panel brands. Among chosen popular 310W photovoltaic panel brands, the best performance photovoltaic panel choice is obtained.

2. Multi-Criteria Decision Making in Photovoltaic Panels Selection

The reason for using an AHP-based decision method approach in this study is that it allows decision makers to analysis complex decision-making problems using a systematic approach that breaks down the primary problem into affordable and simpler sub-problems. In an AHP hierarchy for choosing a solar panel, the goal would be to choose the best panel. This study aims to contribute to the existing literature significantly by helping decision makers in selecting the best solar panel based on various groups of criteria. Electrical, mechanical, financial, environmental, and customer related factors are the five main criteria that are often used in evaluation of various investment projects for making a decision. These criteria can be subdivided into several sub-criteria. In this study, the electrical criterion is subdivided into 15 sub-criteria. The cost criterion is subdivided into variable cost, total investment cost and state support. The environmental criterion involves area requirement and material manufacturing effect. Finally, the customer satisfaction is measured using customer service, availability of spare parts, and reliability. Five alternative solar panels are compared using AHP technique. The hierarchy tree for the selection of the best solar panel is constructed as shown in the Fig. 5.

While measurements for some criteria are readily available, some others like customer satisfaction can only be estimated with respect to other variables. As it is the case in all multi-criteria decision making methods, the relative weights of such criteria need to be determined. In AHP, this is accomplished by pairwise comparison of the elements, starting with the main criteria. Below are the resulting priorities of electrical, mechanical, financial, environmental, and customer related factors.

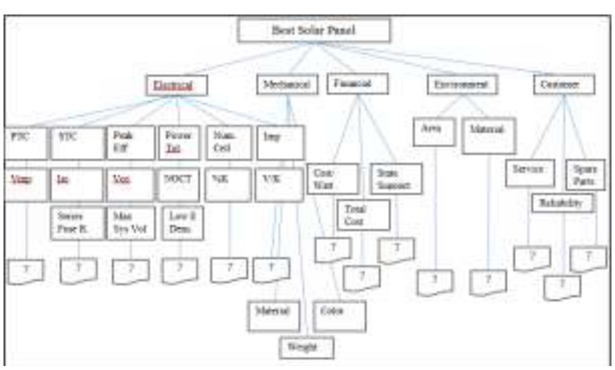


Fig. 5. The hierarchy tree for the selection of the best solar panel

2.1. Priorities

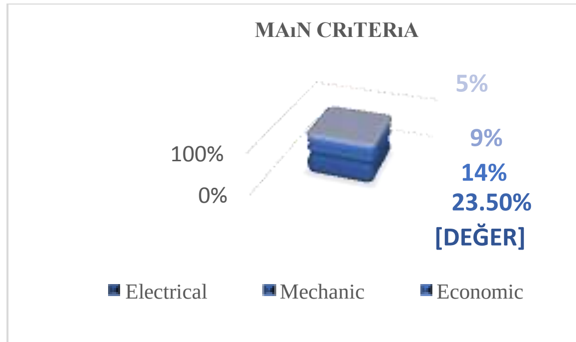


Fig. 6. Main Criteria priorities

Fig. 6 shows main criteria priorities. In the next step, the groups of sub-criteria under each main criterion need to be compared two by two. In the electrical subgroup, each pair of sub-criteria is compared regarding their importance with respect to the electrical criterion. Below are the resulting weights for these criteria.

2.1.1. Electrical Priorities

These are the resulting weights for the criteria based on pairwise comparisons. At this point, the comparison for electrical criterion has been made, and the AHP method has derived the local priorities for this group. These priorities reflect on how much a sub-criterion contributes to the priority of its parent, thus we need to calculate the global priority of each sub-criterion. That will show us the priority of each sub-criterion with respect to the overall goal. The global priorities throughout the hierarchy should add up to one. The global priorities of each electrical sub-criterion are calculated by multiplying their local priorities by the priority of electrical criterion. Fig. 7 displays these values of electrical priorities.

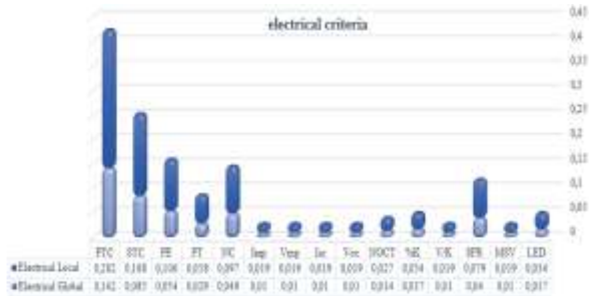


Fig. 7. Electrical Priorities

2.1.2. Mechanical, Financial, Environmental and Customer Priorities

In the financial subgroup, there are three sub-criteria; namely, cost per watt, total cost of investment and state support available. These elements are compared as to how important they are with respect to the financial criterion. These are the resulting weights based on the pairwise comparisons.

Environmental factors considered are the area required to install the panels and environmental effects of the material manufacturing process. Comparison of these elements with respect to the environmental considerations leads to the resulting weights.

Finally, there are three sub-criteria in the customer satisfaction subgroup. These elements are compared as to how they add value towards the customer satisfaction. In order to measure the customer satisfaction towards the solar panels, three sub-criteria are defined: customer service, spare parts available, and the reliability of the company. Service is evaluated to be positively related to the number of branches available for each company. Spare parts are measured by the inventory levels of the companies while the reliability is measured by their market shares and sales. The companies are ranked from 1 to 7 to be able to generate a medium of comparison. Below are the resulting weights of Mechanical, Financial, Environmental and Customer Priorities based on pairwise comparisons [Fig. 8].

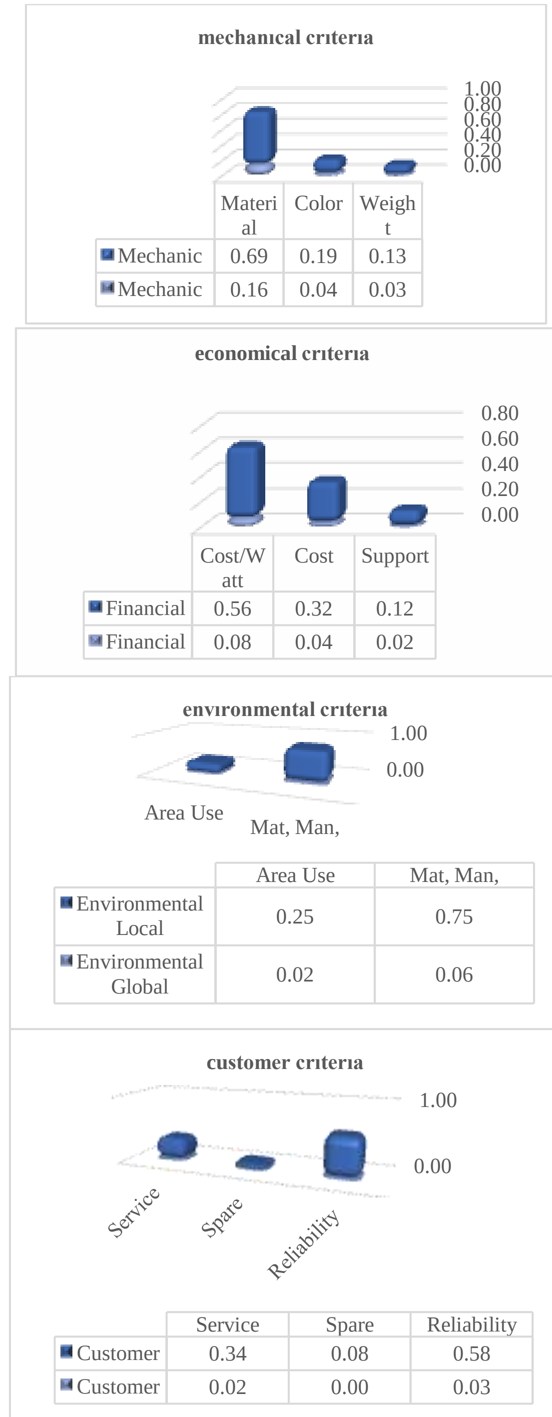


Fig. 8. Mechanical, Financial, Environmental and Customer Priorities

2.1.3. Pairwise Comparison of the Alternatives with Respect to the Criteria

After determining the priorities of each criterion with respect to the overall goal of selecting the best solar panel and priorities of sub-criteria with respect to their associated main criteria, the panel alternatives need to be compared two by two with respect to each sub-criterion. The properties of the selected panels are presented in the Table 1.

The next step in applying the AHP technique is pairwise comparisons of the panel alternatives with respect to each sub-criterion. Remainder of this section presents the priorities obtained under each subcategory using this technique.

Table 1. Solar panel characteristics

	P1	P2	P3	P4	P5	P6	P7
Electrical Properties							
PTC power rating (W)	285 W[1]	280.8 W[2]	277.9 W[1]	283.68 W[2]	275.8 W[2]	285.3 W[2]	280 W[1]
STC Power per unit of area (W/m^2)	157.5	157.2	158.5	159.8	159.8	190.1	158.9
Peak Efficiency (%)	15.75	15.72	15.85	15.98	15.98	19.01	15.89
Power Tolerances (%)	0/+2	0/+3	0/+3	0/+3	-3/+3	-3/+5	0/+2
Number of Cells	72	72	72	72	72	96	72
Imp (A)	8.52	8.08	8.6	8.07	8.35	5.67	8.41
Vmp (V)	36.4	38.4	36.1	38.4	37.1	54.7	36.9
Isc (A)	9.08	8.82	8.9	8.78	8.89	6.05	8.98
Voc (V)	44.9	46	45.3	47.1	45.4	64.4	46.4
NOCT (^0C)	45	45	46	45	45	-	46
Temp. Coefficient of Power (%K)	-0.41	-0.43	-0.43	-0.41	-0.47	-0.38	-0.45
Temp. Coefficient of Voltage (V/K)	-0.139	-0.138	-0.145	-0.141	-0.158	-0.177	-0.153
Series Fuse Rating (A)	15	15	15	15	15	20	15
Maximum System Voltage (V)	1000	1000	1000	600	600	1000	600
Lower energy density(W/m^2)	15.35	15.19	15.87	16.24	16.56	16.78	16.03
Mechanical Properties							
Type	Policrystalline	Policrystalline	Policrystalline	Monocrystalline	Monocrystalline	Monocrystalline	Policrystalline
Output Terminal Type	Amp henol	Multi conta	Multi conta	Multi conta	Multi conta	Multi conta	Amp henol
Frame Color	bronze	clear	clear	clear	clear	White	clear
Length* Width* Depth (mm)	1972*998*40	1956*992*50	1960*998*50	1956*992*45	1956*992*45	1559*1046*46	1970*990*50
Weight (kg)	27.5	27	23.2	27	23.2	18.6	26.8
Financial Properties							
Support of government	0.25	0.25	0.22	0.35	0.32	0.25	0.36
Price	$240	$611.00	$592.00	$589.00	$673.00	$608.45	$679.00
Cost per Watt	$0.76	$1.97	$1.91	$2.18	$1.98	$2.20	$2.10
Customer Satisfaction							
Service support	6	7	6	4	5	2	3
Spare part	5	6	7	5	4	3	1
Reliability	5	7	6	5	2	3	4

2.1.4. Rating Priorities

These are the resulting weights for the criteria based on pairwise comparisons. Fig. 9 shows rating priorities of electrical characteristics. Priorities of mechanical, financial, environmental, and customer characteristics are displayed in Fig. 10.

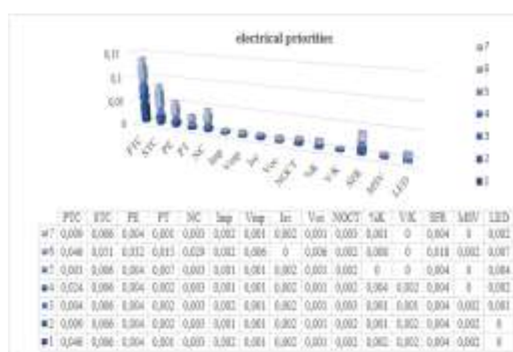


Fig 9. Electrical Priorities

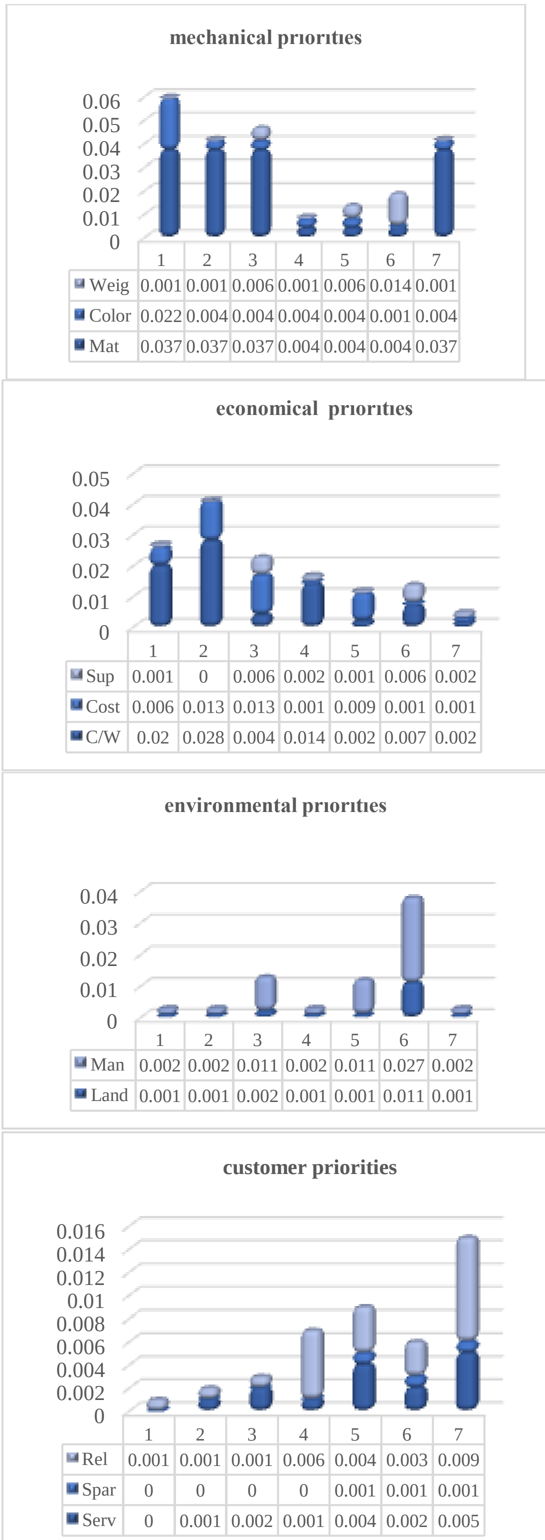


Fig 10. Mechanical, Financial, Environmental, and Customer Priorities

3. Experimental Results and Discussions

This paper is based on schema from investigations in the photovoltaic technology, existing literature, and ideas with photovoltaic industry experts from photovoltaic manufactures, and solar panel companies.

While energy is being one of the most important sources for economic development and fossil fuels keeps depleting exponentially, renewable energy has been recognized as the last resort for future economic development. Solar energy is expected to be the most promising renewable energy source, and the construction of solar energy plants is the elementary step for a long-term operation.

The factors for achieving the goal are listed first through literature review and interview with experts, and they are used to construct a network with five major criteria, namely, electrical, mechanical and financial features, environmental effects and customer satisfaction levels. Each category is evaluated through a series of sub-criteria. By adopting a hierarchical modeling, the interrelationships among sub-criteria under each criterion are determined. After questionnaires are filled out by experts, analytic hierarchy process is used to calculate the importance of the criteria and the sub-criteria and to evaluate the expected overall performance of the solar panels.

With the implementation of the model, the most suitable type of panels can be selected for constructing the solar plants. The model can also be adjusted as required to help evaluate other renewable energy equipment.

In the case study, electrical category is the most important criterion, followed by mechanical features. Under the electrical category, PTC power rating is the most important objective of the experts, followed by the STC power per unit of area. This means that the PTC power rating is the most important factor in selecting solar panels. Under the mechanic characteristics, material type is the highest concern. Material manufacturing process has the biggest priority among the environmental criteria. Under the customer satisfaction category, reliability is the criterion with the highest priority.

Based on the calculations, the relative priorities corresponding to the attractiveness of each solar panel about all factors of electrical, mechanical, financial, environmental and customer satisfaction are presented below [Fig. 11]. The table below indicates that P6 is the panel that contributes most to the overall goal in terms of electrical properties with a global priority of 0,224 which is considerably high compared to the remaining alternatives.

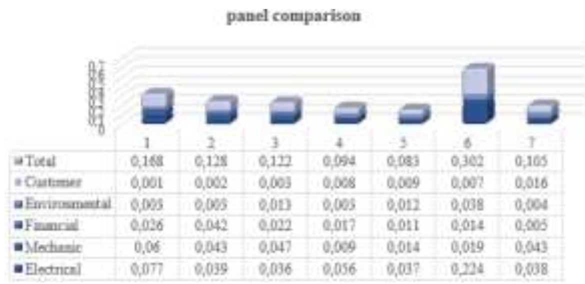


Fig 11. Panel Comparison

Table also presents the global mechanic priorities of the panels and according to the results, P1 is the best alternative that contributes the most to the overall goal of selecting the best solar panel, P3 is ranked second with a small difference. The table indicates that P2 has the highest global priority in terms of financial considerations, with a considerable difference with the other alternatives. Environmental priorities listed in the table shows that P6 is by far the leading panel towards the overall goal from the environmental perspective. The final columns presenting the customer service related priorities indicate that P6 is the alternative with highest scores in terms of customer satisfaction and contributes the most towards the overall goal.

In overall, adding the global priorities in all categories, the obtained results indicate that the model P6 is the alternative that contributes the most to the goal of choosing the best solar panel that satisfies all the criteria selected. High priority values of P6 in electrical and customer related categories have resulted in favorable overall outcome.

After considering electrical, mechanical, financial, environmental and customer satisfaction performance of each panel we can conclude that P6 is the most suitable one that can be used in a solar plant. Although the results may be case specific, the proposed model can be tailored and applied to other cases in different locations or countries as a reference when selecting the most appropriate solar panels.

References

1] Nguyen, T.L.T., Hermansen, J.E., 2012. System expansion for handling co-products in LCA of sugar cane bio-energy systems: GHG consequences of using molasses for ethanol production. Applied Energy 89: 254-261.

[2] http://energyinformative.org/cheapest-best-value-solar-panels/

[3] Jain PC. A model for diffuse and global irradiation on horizontal surfaces. Sol Energy 1990;45:301–8.

[4] SPE, Global market outlook 2015 with industry average.

[5] Solar Electric System Design, Operation and Installation An Overview for Builders in the U.S. Pacific Northwest, October 2009.

[6] Dincer F.Overview of the photovoltaic technology status and perspective in Turkey. Renew Sustain Energy Rev 2011;15(8):3768–79.

[7]https://en.wikipedia.org/wiki/Growth_of_photovoltaics#Forecast

[8]Chen AA, Forrest W, Chin PN, McLean P, Grey C. Solar radiation in Jamaica. Sol Energy1994;53(5):455–60.

[9] Saaty T L, Decision making with the analytic hierarchy process, Int. J. Services Sciences, Vol. 1, No:1, 2008 83

[10] Cavallaro, F. A. 2010. comparative assessment of thin-film photovoltaic production processes using the ELECTRE III method. Energy Policy 38: 463–474.

[11] Chen, H.C. & Yang, C.H. 2014. A Multi-Criterion Analysis of Cross-Strait Co-Opetitive Strategy in the Crystalline Silicon Solar Cell Industry. Mathematical Problems in Engineering. Article ID 687942, 11 pages, http://dx.doi.org/10.1155/2014/687942.

[12] Naghiu, G.S., Giurca, I., Achilean, I. & Badea, G. 2016. Multicriterial Analysis on Selecting Solar Radiation Concentration Ration for Photovoltaic Panels Using Electre-Boldur Method. 9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, Tirgu-Mures, Romania (Procedia Technology) 22: 773 – 780.

[13] Guenounou, A., Malek, A. & Aillerie, M. 2016. Comparative performance of PV panels of different technologies over one year of exposure: Application to a coastal Mediterranean region of Algeria. Energy Conversion and Management 114: 356–363.

[14] Khorasaninejad E, Fetanat A, Hajabdollahi H. Prime mover selection in thermal power plant integrated with organic Rankine cycle for waste heat recovery using a novel multi criteria decision making approach. *Applied Thermal Engineering* 2016; **102**: 1262–1279.

[15] Amin N, Lung C, W Sopian K. A practical field study of various solar cells on their performance in Malaysia. *Renewable Energy Journal* 2009; **34**(8): 1939-1946.