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Photovoltaic Panel Selection: AHP Approach

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***Abstract*— Solar power is a significant renewable energy resource to petrol-based alternatives and theoretically the most inexhaustible, clean and abundant one in the world. The energy from sun snatched by the Earth is approximately 1.8×1011 MW, which is many times bigger than the existing rate of all the energy expenditure. Photovoltaic conversion is one of the best ways to harness the solar energy with the decreased management and operating costs, though still very expensive, due to the nonexistence of moving devices. At the photovoltaic system project, the initial setup cost is very high and the cost of solar panels is about 40-50% of total system costs. There have been numerous efforts by researchers worldwide cooperating to reduce costs of photovoltaic panels, efficient novel products and to improve their energy efficiency and procreate innovative practices based on photovoltaic system design technology.**

In this study, photovoltaic panel evaluation approach is applied, which covers mechanical, electrical, environmental, economic, and customer-related criteria. And then, the comparative assessment of diverse photovoltaic panel brands is performed by using the AHP (The Analytical Hierarchy Process) approach. Among chosen popular brands for 240W, the most convenient photovoltaic panel choice is made by evaluating comparatively. The data is obtained from the popular photovoltaic panel datasheet.

***Index Terms*— Photovoltaic panel, Analytical Hierarchy Process, Sustainable energy, Solar energy, Renewable resource.**

I. INTRODUCTION

Solar energy is a significant resource of sustainable energy in the World. Fig.1 shows the solar radiation potential in the World [1].

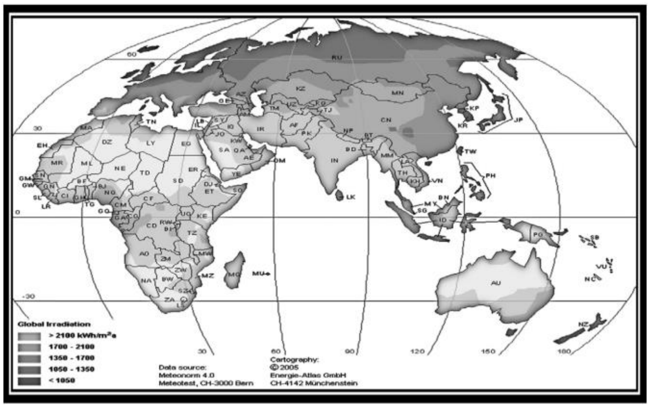

Fig. 1. The solar radiation potential in the World.

Solar photovoltaic power systems are able to provide electrical energy to a given load by directly transforming solar energy owing to the photovoltaic impact [2, 3]. A structure of solar system is very changeable. Solar systems can be very simplistic, formed of only a photovoltaic panel and load, as in the direct powering of a water pump motor, which only requires to operate when the sun's rays hit the surface of panels. The photovoltaic panels are the primary building blocks; these can be arranged into arrays to rise electrical energy generation. The additional devices are normally needed to convert energy into stored energy or other useful forms. The resulting system will therefore be determined by the energy requirement in a particular implementation. The photovoltaic impact is the main physical process toward which a photovoltaic panel transforms sun's ray into electrical energy. Sun's ray is created by particles or photons of photovoltaic energy. These photons include diverse quantity of energy suitable to the diverse wavelengths of the photovoltaic spectrum. When photons hit a photovoltaic panel, they may be absorbed or reflected. Solely the absorbed photons manufacture electricity. In this form, the energy of the photon is converted to an electron in an atom of the panel [4, 5].

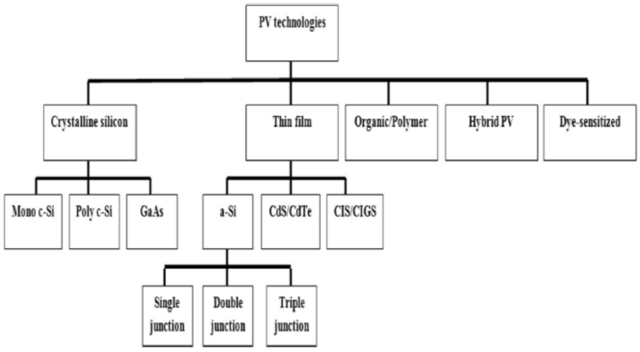

Fig. 2. The classification of solar panel materials

The general classification of solar panel materials is given Fig. 2 [5]. Silicon is the widespread material used in production process of photovoltaic panels. Monocrystalline photovoltaic panels are composed of a crystal. The manufacturing methods are expensive and difficult. Monocrystalline photovoltaic panels tend to be more expensive, though more effective (more energy in smaller field). The manufacturing process of multi-crystalline photovoltaic panels allows multiple crystalline structures to be composed within the panel. This process is easier to be applied in a manufacturing line. It is relatively more inexpensive than monocrystalline photovoltaic panels at the cost of lower effectiveness. It uses less silicon to produce the thin-film photovoltaic panels allowing for cheaper manufacturing expenses. The thin-film solar panels tend to be more inexpensive but has also lower performance. The solar energy system cost covers all of the diverse device cost. Fig. 3 displays the components of a typical c-Si PV module, illustrating a simple off-grid PV system with AC and DC loads [4].

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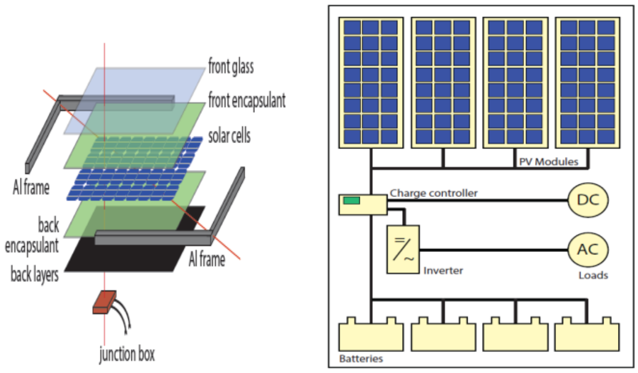


(a) (b)

Fig. 3. (a) The components of a typical c-Si PV module (b) Illustrating a simple off-grid PV system with AC and DC loads [4]

The Analytical Hierarchy Process is one of the most popular and powerful multi-criteria approaches for effective decision making, using an advisable project plan. In a hierarchical design, AHP is a multi-criteria decision making method that facilitates complex, bad-constructed problems by working-out the decision factors [6].

In the last years, researchers have begun to focus on the evolution for equipment related to sustainable energy. The Onicescu method used for selecting the optimum multi-junctions solar panel at the photovoltaic energy system by Badea et al. [7]. Naghiu et al. analyzed the choice of the optimum solution concerning the concentration ratio of the solar panels with Electre-Boldur Method [8]. Zeyuan compared to different kinds of solar cell and analyzed with TOPSIS [9]. Beltran et al. made the choice of solar energy projects by an ANP model. The impacts between the parameters of the net (such as alternatives and risks) detected and investigated using the two different ANP methods [10]. Şahin et al. investigated the selection of the most appropriate solar panel which is monocrystalline for the three provinces (Adana, Yozgat and Sinop) of Turkey by using both solar home system model and AHP [11]. A hybrid multi criteria analysis based on the fuzzy PROMETHEE, fuzzy DEMATEL and fuzzy ANP, used to selection the best option among the photovoltaic panel, fuel cell, gas engine, diesel engine, and gas turbine by Khorasaninejad et al. [12]. The PROMETHEE method suggested choosing technical resolutions in event of multi-junction solar panels by Giurca et al. [13]. Amin et al. developed area study of different PV panels on their performance [14]. In the Mediterranean region, Stamatakis et al. analyzed with multi-criteria decision making method of solar panels affixed on characteristical south-covering shading devices of buildings [15]. For energy management, Salah et al proposed a multi-criteria fuzzy algorithm in order to connect native apparatus on solar panel [16].

This article focusing on photovoltaic panel selection, reveal the evaluation of the existing primary market brands, using the approach of the AHP. For the purpose of this research, the photovoltaic panel brands with the same power generation capacity is used. The photovoltaic panels are compared based on environmental, economic, customer satisfaction criteria, in addition to mechanical and electrical properties of the different existing light absorbing materials used. Within these five categories, many sub-criteria are determined; similarly, sub-options are noted for each of the solar panel brands. Expert opinions and literature review have been used to reach at qualitative and quantitative evaluations.

II. Multi-Criteria Decision Making in Photovoltaic Panels Selection

The reason for using an AHP-based decision analysis approach in this study is that it allows decision makers to analyze complex decision-making problems using a systematic approach that breaks down the main problem into simpler and affordable 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. 4.

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.

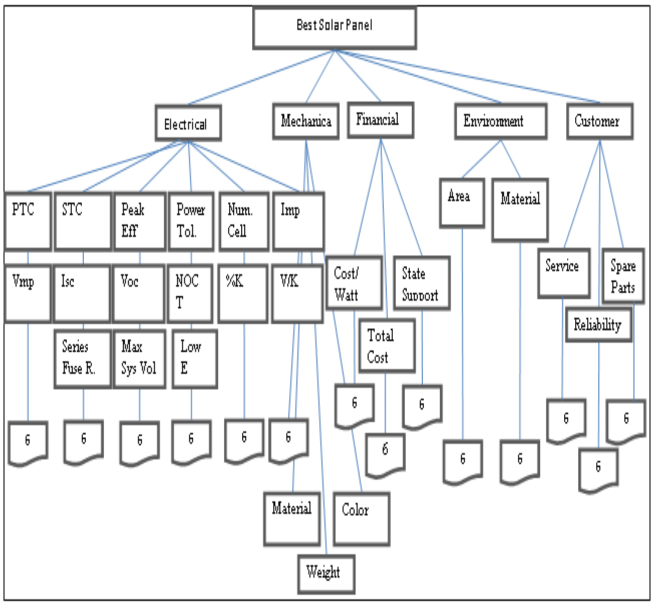


Fig. 4. The hierarchy tree for the selection of the best solar panel.

1.1. Priorities

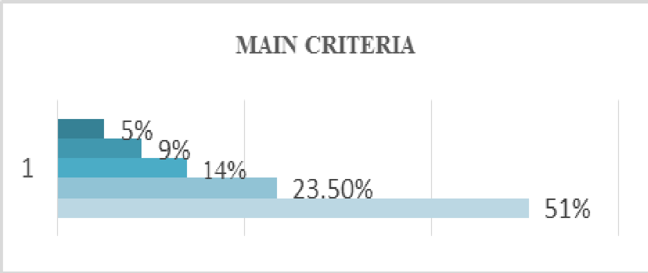


Fig. 5. Main Criteria priorities

1) Fig. 5 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.

1.1.1. 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 approach 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. 6 displays these values of electrical priorities.

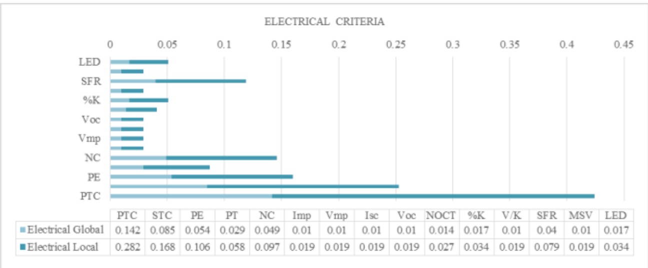


Fig. 6. Electrical Priorities

1.1.2. 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 6 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. Mechanical, Financial, Environmental and Customer Priorities are shown in Fig. 7.

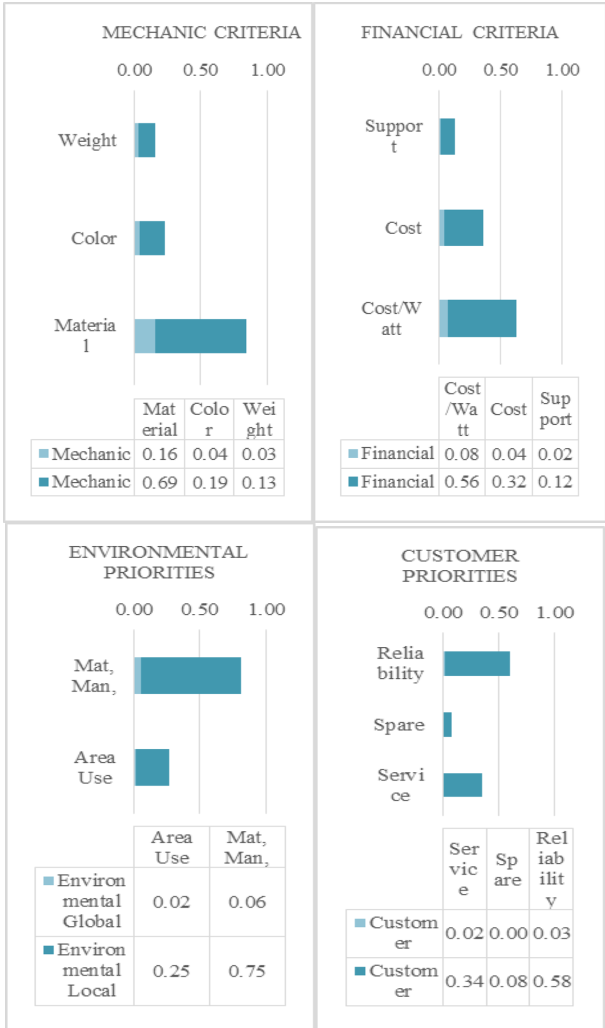


Fig. 7. Mechanical, Financial, Environmental and Customer Priorities

1.1.3. 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.

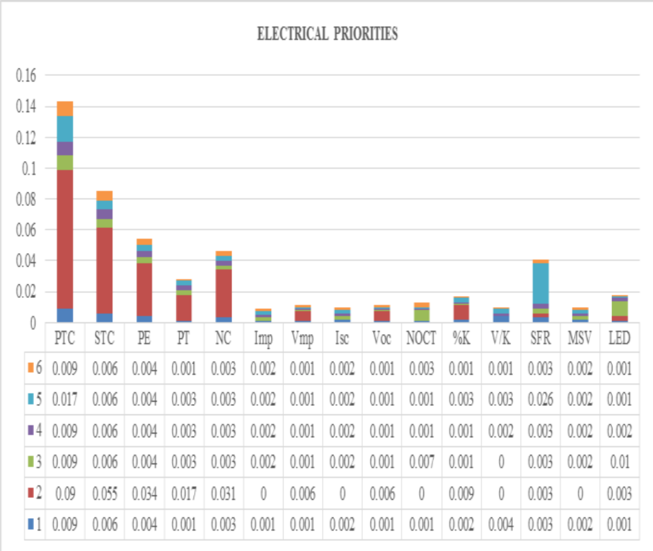
The next step in applying the AHP technique is pairwise comparisons of the panel alternatives with respect to each sub-criterion. Remainder of this section presents the priorities obtained under each subcategory using this technique.

Table 1. Solar panel characteristics

	P1	P2	P3	P4	P5	P6
Electrical Properties						
PTC power rating (W)	216.2W[1]	226.57W[2]	216.4W[1]	217.18W[3]	217.4W[1]	217W[1]
STC Power per unit of area (W/m^2)	13.6W/ft^2 (146.6W/m^2)	17.7W/ft^2 (190.3W/m^2)	13.7W/ft^2 (147.2W/m^2)	13.7W/ft^2 (147.5W/m^2)	13.5W/ft^2 (145.5W/m^2)	13.6W/ft^2 (146.9W/m^2)
Peak Efficiency (%)	14.66	19.03	14.72	14.75	14.55	14.69
Power Tolerances (%)	0/+3	-5/+10	0/+5	0/+5	0/+5	0/+2
Number of Cells	60	72	60	60	60	60
Imp (A)	7.95A	5.51 A	8.19 A	8 A	8.11 A	8.14 A
Vmp (V)	30.2V	43.7 V	29.3 V	30 V	29.6 V	29.5 V
Isc (A)	8.45 A	5.85 A	8.75 A	8.57 A	8.46 A	8.65 A
Voc (V)	37.3 V	52.4 V	37.5 V	35.7 V	36.9 V	37.5 V
NOCT (^{0}C)	45	44	47.5	45	45	46
Temp. Coefficient of Power (%K)	-0.41	-0.3	-0.48	-0.45	-0.4	-0.45
Temp. Coefficient of Voltage (V/K)	-0.112	-0.131	-0.135	-0.118	-0.116	-0.124
Series Fuse Rating (A)	15	15	15	15	20	15
Maximum System Voltage (V)	600	43.7	600	600	600	600
Lower energy density(W/m^2)	10.55	10.82	11.60	10.68	10.36	10.55
Mechanic Properties						
Type	Monocrystalline Silicon	Monocrystalline Amorphous Hybrid	Policrystalline Silicon	Policrystalline Silicon	Policrystalline Silicon	Policrystalline Silicon
Output Terminal Type	Multicontact Connector Type4	Multicontact Connector Type 3	Multicontact Connector Type 4	Multicontact Connector Type 4	Multicontact Connector Type 4	Multicontact Connector Type 4
Frame Color	clear	clear	clear	clear	black	white
Length* Width* Depth (mm)	1650*992*45	1580*798*35	1640*994*46	1640*992*40	1665*991*50	1650*990*50
Weight (kg)	19	15	19	18.5	19.8	19.1
Financial Properties						
State Support	0.25	0.28	0.23	0.25	0.20	0.23
Price	$240	$295	$287	$280	$250	$275
Cost per Watt	$0.76	$0.95	$0.90	$0.86	$0.80	$0.88
Customer Satisfaction						
Service support	6	2	1	3	5	4
Spare part	5	2	1	4	6	3
Reliability	5	1	3	2	6	4

1.1.4. Rating Priorities

These are the resulting weights for the criteria based on pairwise comparisons. Fig. 7. shows rating priorities of electrical characteristics. Priorities of mechanical, financial, environmental, and customer characteristics are displayed in Fig.8.



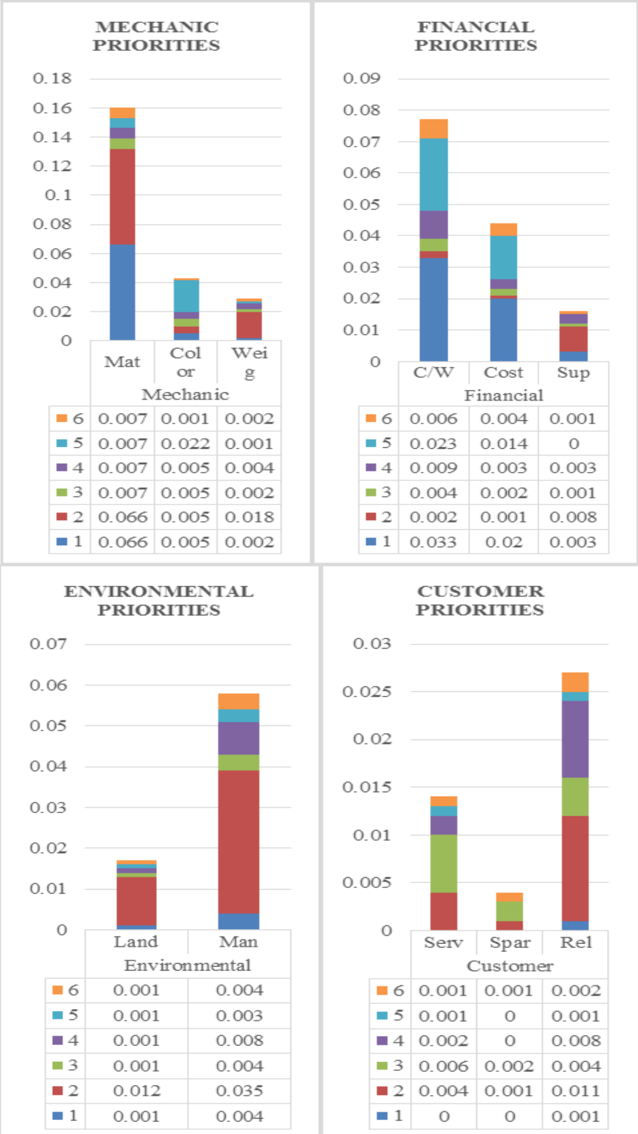


Figure 8. Mechanical, Financial, Environmental, and Customer Priorities

III. Experimental Results and Discussions

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

While energy is being one of the most significant resources for economic growth and fossil fuels keep being consumed exponentially, sustainable energy has been known as the current remedy for future economic improvement. Solar energy is awaited to be the most encouraging sustainable energy resource, and the structure of solar energy systems is the fundamental step for a long-term process.

As a first step in the application of the selected method, the factors for obtaining the target are listed first through interview with specialists and literature review, and these factors are used to build a system with five primary criteria; electrical, mechanical and financial features, along with environmental effects and customer satisfaction levels. Each category is evaluated through a series of sub-criteria. The relationships between sub-criteria beneath each of the criteria are obtained by adopting a hierarchical approach. After survey questions are answered by experts, AHP is used to compute the significance of the main and sub-criteria to assess the anticipated efficiency of the solar panels.

With the application of the AHP approach, the most convenient type of photovoltaic panels can be chosen for composing the solar plants. The AHP approach can also be organized as needed to help assessing other sustainable energy devices.

In this work, electrical category is the most significant 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. The figure below indicates that P2 is the panel that contributes most to the overall goal in terms of electrical properties with a global priority of 0,257 which is considerably high compared to the remaining alternatives.

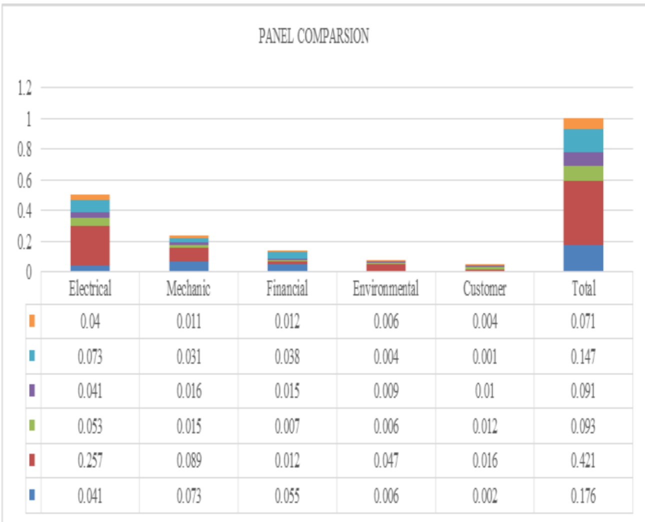


Fig. 9. Panel Comparison

Table also presents the global mechanic priorities of the panels and according to the results, P2 is once again the best alternative that contributes the most to the overall goal of selecting the best solar panel, while P1 is ranked second with a small difference and there is a big gap with the remaining panels.

The table also indicates that P1 has the highest global priority in terms of financial considerations, with a considerable difference with the other alternatives.

Environmental priorities listed in the Figure 3 shows that P2 is by far the leading panel towards the overall goal from the environmental perspective.

The fifth column presenting the customer service related priorities indicates that P2 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 P2 is the alternative that contributes the most to the goal of choosing the best solar panel that satisfies all the criteria selected.

After considering electrical, mechanical, financial, environmental and customer satisfaction performance of each panel we can conclude that P2 is the most suitable one that can be used in a solar plant. Though the conclusions may be case sensitive, the suggested approach can be applied and tailored to other cases in diverse countries or locations as a reference when choosing the most convenient solar panels.

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