Selection of Solar Panels Based on Brand Using Fuzzy AHP – TOPSIS Method

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Abstract

The development of renewable energy has provided Indonesia with an opportunity to tap into its solar energy potential, which amounts to a staggering 207 GW. This opportunity is further driven by the increasing demand for electricity, the aging and inefficient fossil fuel power plants, the declining costs of solar panel installations, and the ease of their deployment. However, customers often encounter challenges in selecting the appropriate solar panels. These challenges stem from various factors, including the lack of easily accessible product information, the multitude of alternatives with diverse parameters in solar panel selection, and the absence of brand-specific recommendations for implementing solar panel types. Consequently, customers face difficulties in making informed decisions, potentially hindering the acceleration and optimization of solar panel expansion plans while also increasing the risk of investment errors. Solar panels come in various types based on their brands, and each brand possesses distinct advantages and disadvantages, making it difficult to determine the most optimal choice for implementation. Therefore, a selection process is necessary to identify the most suitable solar panel type based on brand, utilizing the Multi-Criteria Decision Making (MCDM) method known as Fuzzy AHP-TOPSIS. This method will evaluate nine alternative monocrystalline solar panel types, each with a power rating of 540 watts peak, sourced from different brands. The evaluation will be based on validated criteria established through expert assessments. By implementing this method, customers will be empowered with a systematic approach and better recommendations for selecting solar panel products.

Keywords
Photovoltaic, Solar Panel, Multi-Criteria Decision Making, Fuzzy AHP – TOPSIS, and Technology Selection.

1. Introduction
In the realm of renewable energy adoption, Indonesia holds substantial potential. Geographically, Indonesia is situated within the "Sunshine Belt," spanning between 35 degrees North and 35 degrees South, allowing for abundant solar irradiation throughout the year. The daily average solar irradiation potential received by Indonesia is approximately 4.8 kWh/m² (Global Solar Atlas 2018).

Additionally, Indonesia has taken part in global efforts to combat climate change, as evidenced by its commitment under the Paris Agreement of 2015. The nation pledged to independently reduce carbon emissions by 29% and up to 41% with international assistance by 2030 (United Nations Climate Change 2022). In line with the ratification of the Paris Agreement through Law No. 16 of 2016, Indonesia has committed to transitioning from fossil fuels to renewable energy sources. The target is to achieve a renewable energy mix of 23% by 2025 (Presiden Republik Indonesia 2016). In 2017, the energy sector accounted for 49% of greenhouse gas emissions (including mining, oil and gas, transportation, and power generation). Specifically, power generation and transportation contributed to 34% of the

total emissions (Kementerian Lingkungan Hidup dan Kehutanan Direktorat Jenderal Pengendalian Perubahan Iklim, 2019). Achieving the 34% target would enable Indonesia to meet its Paris Agreement commitments independently.
Indonesia's National Energy General Plan (RUEN) outlines the vast renewable energy potential, equivalent to a power generation capacity of 443.2 GW, with solar energy potential alone reaching 207 GW (Presiden Republlik Indonesia 2017) . Indonesia possesses favorable conditions for solar panel implementation, including a geographically strategic location with a vast land area of 1.92 million km², providing ample space for widespread solar panel adoption. The average solar irradiation of 4.8 kWh/m²/day further enhances the viability of solar energy utilization (Direktorat Jenderal Ketenagalistrikan Kementerian Energi dan Sumber Daya Mineral 2020). Additionally, Indonesia boasts extensive lakes covering an area of 121,000 km² and calm sea waters within its archipelagic and internal seas, totaling 3.1 million km² with relatively low wave height. Furthermore, rooftop solar panels have significant potential, estimated between 34 and 116 GW (Saputra 2019).

In addition to geographical advantages, several other factors contribute to the opportunities for solar panel development in Indonesia. The escalating demand for electricity in the country underscores the need for alternative energy sources. Each year, there is a per capita increase in electricity consumption, with a projected electricity demand of 3.3 MWh per capita by 2038. The competitive pricing of solar panels, coupled with their declining costs, positions them favorably compared to other renewable energy sources. Moreover, the existing fossil fuel power plants in Indonesia are aging and reaching the end of their operational lives. These plants have become inefficient in terms of electricity generation, cost, and environmental impact. This scenario highlights the enormous potential for solar panels to replace fossil fuel power plants. Furthermore, solar panel installations require a relatively shorter construction period compared to fossil fuel-based power plants. This is facilitated by the modular nature of solar panel systems and their plug-and-play mechanisms.
Despite its immense potential and opportunities, Indonesia has yet to achieve its targets and ambitions. One of the contributing factors is the challenge faced by individuals interested in utilizing solar panels in selecting the appropriate and optimal panel type. This challenge is aggravated by the limited availability of easily comprehensible product information and the multitude of alternatives with diverse parameters in solar panel selection. Often, subjective parameters such as seeking the cheapest or most efficient panel are used, although the cheapest panel may not necessarily be the most efficient, and vice versa. Such suboptimal decision-making can lead to investment errors and impede the timely expansion and utilization of solar panels. Furthermore, the various brands of solar panels further complicate the selection process. Each brand offers unique advantages and disadvantages across several key criteria, including electrical, mechanical, economic, environment, and customer satisfaction. These complexities necessitate the provision of brand-specific recommendations to facilitate the optimal selection of solar panel products.
In general, this research aims to determine the selection of solar panel types based on brands for monocrystalline panels with a power rating of 540 watts peak. The study seeks to analyze the interrelationships between various criteria and available alternatives to generate recommendations for the selection of solar panel types. These recommendations aim to accelerate and optimize solar panel expansion plans in Indonesia.

1.1 Objectives
The main objectives of this research are to analyze the selection of solar panel types based on brands and provide recommendations for implementing specific brands. The analysis involves evaluating various dimensions and parameters, such as electrical, mechanical, economic, environmental, and customer satisfaction aspects. By utilizing the Multi-Criteria Decision Making (MCDM) method, specifically Fuzzy AHP-TOPSIS, this research aims to offer comprehensive insights into the advantages and disadvantages of different solar panel brands. The recommendations derived from the evaluation results will assist customers in making informed decisions and optimizing solar panel expansion plans in Indonesia. Ultimately, this research aims to contribute to the efficient and effective utilization of solar energy by facilitating the selection of optimal solar panel types based on brand considerations.

2. Literature Review
In the process of providing recommendations, the selection process will employ the Multi-Criteria Decision Making (MCDM) method. Several research studies have been conducted to determine decision-making and recommendation approaches. Ahmetovic et al. (2022) conducted research to determine the optimal location for solar panel systems in order to maximize additional energy generation. They utilized the Fuzzy AHP method to prioritize criteria and address the subjectivity of the AHP method. Bouzid et al. (2021) conducted a study using the SWARA-TOPSIS and SWARA-VIKOR methods with an integrated approach to determine the best-performing solar panel brand for a company. The results obtained from TOPSIS and VIKOR differed significantly due to variations in aggregation functions and

normalization methods. Setiawan et al. (2020) conducted research on the selection of the best charging station technology adoptable in Indonesia. The study combined the AHP and TOPSIS methods, and the overall weight calculation was performed using the geometric mean. Yang et al. (2011) conducted a study to determine solar panel modules for a large-scale system, specifically a 100 MW VLS-PV power generation system to be installed in the Gobi Desert. They considered economic and environmental perspectives using the Improved AHP method with a quasioptimal matrix and a readjusted weights factor to mitigate the uncertainty of pair-wise comparison due to subjective personal judgment. Prajapati et al. (2021) developed a recommendation system to rank two-wheeler electric vehicles for purchasing in the Indian market. They employed the Fuzzy AHP-TOPSIS method to generate recommendations. Based on their research, there is a need for a comparative analysis covering global alternatives and further studies in different regions, considering criteria such as geological conditions, government policies, and market demand. Balo and Şağbanşua (2016) conducted research to determine the best solar panel brand among 200 W panels using the AHP method. Additionally, Kusumawardani et al. (2015) conducted research using the Fuzzy AHP-TOPSIS method to assist in the HR manager selection process. The utilization of fuzzy logic in the method was due to the difficulty of ensuring consistent and bias-free decisions.

To accomplish the objectives of this research, the study conducts a literature review to gather a list of criteria and sub-criteria. This list is then compiled into a questionnaire, which is evaluated by experts. To quantify the expert judgments, various indices discussed by Almanasreh et al. (2019) are considered, including the Content Validity Ratio (CVR), Content Validity Index (CVI), and Modified Kappa. In this paper, the CVI and Modified Kappa methods are used. CVI is widely used to measure the content validity of an instrument. The experts are asked to rate the relevance of each item on a 4-point ordinal scale: "1 = not relevant, 2 = somewhat relevant, 3 = quite relevant, and 4 = highly relevant." The use of a 4-point scale avoids a neutral midpoint value (Polit and Beck 2006). For each item, an item-level CVI (I-CVI) is calculated by dividing the total number of experts who rated it as 3 or 4 (relevant) by the total number of experts. The I-CVI values should be equal to or greater than 0.75. This criterion is based on the Kappa value, which needs to be greater than or equal to 0.6 to be considered a valid and acceptable indicator (Fleiss 1981). Additionally, the S-CVI value can be obtained by dividing the total I-CVI of all indicators by the total number of items. An S-CVI value above 0.80 indicates that all relevant indicators and expert input are acceptable (Polit and Beck 2006).

3. Methods

This research was started by validating the criteria from experts by giving the first stage of the questionnaire. This aims to find out whether the related sub-criteria have an important role in the selection of solar panels. The validated sub-criteria will be selected using the I-CVI method, then the validated sub-criteria will be further used in research if it exceeds the calculation threshold value. After that, the relationship between criteria and between sub-criteria also requires an assessment from experts by giving the second stage of the questionnaire. From this, the author can calculate the weight of the criteria and sub-criteria using the Fuzzy AHP approach which will then be processed with the TOPSIS approach to obtain a ranking of the criteria and sub-criteria that influence the selection of solar panels.

3.1 CVI Method

Content validity is a crucial step in assessing the adequacy of items representing a research concept, determining whether the content coverage of the research concept is sufficiently represented by those items (Waltz et al., 2005). This study utilizes expert opinions to establish the Item-Level Content Validity Index (I-CVI) and the Scale-Level Content Validity Index (S-CVI) (Polit et al. 2007). The assessment of content validity requires a minimum of three experts (Lynn, 1986). An expert evaluates the questionnaire items based on a four-point scale of relevance: (1) not relevant, (2) somewhat relevant, (3) quite relevant, and (4) highly relevant (Polit et al. 2007). These four scale points are employed to avoid ambiguity and the selection of neutral values by experts (Shrotryia and Dhanda 2019).

The calculation of I-CVI involves determining the number of experts who agree by assigning a relevance rating of 3 or 4, which is then divided by the total number of experts involved. The formula for calculating I-CVI is represented by the equation below (Polit et al. 2007). For example, if an item receives ratings of 3 or 4 from four out of five experts, the I-CVI value for that item would be 0.80. The value of k* was obtained using formula 3.3, and a kappa value above 0.60 was considered good/substantial, indicating that the driver or barrier is relevant. If the kappa value is below 0.60, the factor is considered irrelevant (Almanasreh et al. 2019).

$$Pc = \left[\frac{N!}{A!\,(N-A)!}\right] 0.5^{N} \quad \text{.... formula 3.1}$$

In this formula 3.1,
Pc = “probability of chance agreement”
N = “number of experts in a panel”
A = “number of panellists who agree that the item is relevant”

$$I-CVI = \frac{number\ of\ experts\ who\ rated\ the\ item\ as\ 3\ or\ 4}{number\ of\ total\ experts} \quad \text{… formula 3.2}$$

$$k* = \frac{I-CVI - Pc}{1 - Pc} \quad \text{… formula 3.3}$$

After calculating the I-CVI values, the S-CVI is computed by dividing the total sum of I-CVI values for all items by the total number of items. The formula for calculating S-CVI is illustrated by the equation below. The computation of S-CVI is performed to ensure the overall scale-level content validity. A recommended threshold for S-CVI is a minimum of 0.80 to represent overall content validity (Lynn 1986; Polit et al. 2007).

$$S-CVI = \frac{\sum I-CVI}{total\ item} \quad \text{… formula 3.4}$$

The Table 1 below demonstrates the I-CVI values with different numbers of experts and their agreements. This study involved four experts for content validity assessment, where an I-CVI value of at least 0.75 was required for an item to be considered "good" on evaluation. This indicates that a minimum of three experts provided ratings of 3 (relevant) and 4 (highly relevant) on the questionnaire. Therefore, the collected item elements from the literature study are valid and can be considered for further analysis in the subsequent research stages.

Table 1. I-CVI Evaluation

Number of Experts	Number of Experts who Agree	I-CVI[a]	Pc[b]	K*[c]	Evaluation
3	3	1,00	0,125	1,00	Excellent
3	2	0,67	0,375	0,47	Fair
4	4	1,00	0,063	1,00	Excellent
4	3	0,75	0,25	0,67	Good
5	5	1,00	0,041	1,00	Excellent
5	4	0,80	0,156	0,76	Excellent
6	6	1,00	0,016	1,00	Excellent
6	5	0,83	0,094	0,82	Excellent
6	4	0,67	0,234	0,56	Fair

3.2 Fuzzy AHP

After achieving validated criteria, it can be assessed with Fuzzy AHP to make weighting of each element. Weighting involves assessing the relative importance of each element in decision-making objectives using pairwise comparison methods. The data used consists of linguistic values provided by experts. The steps for weighting each element are calculating the combined pairwise comparison values of all experts for inter-factor weights using linguistic terms. Next, we can convert numerical values into Triangular Fuzzy Numbers (TFN) in the form of (l, m, u). For example, if the decision-maker states that "Factor 1 is weakly important than Factor 2," this assessment is transformed into a TFN value with l = 2, m = 3, u = 4, or written as (2, 3, 4). Conversely, in the pairwise comparison contribution matrix of factors, the comparison of Factor 2 with Factor 1 will take the form of a fuzzy triangular scale such as (1/4, 1/3, 1/2). The Table 2 below represents fuzzy scale used for this research.

Table 2. Numerical Scales and Fuzzy Linguistics

Value	Description	Triangular Fuzzy Scale	Triangular Fuzzy Reciprocal Scale
1	Equally Important	(1,1,1)	(1,1,1)
3	Weakly Important	(2,3,4)	(1/4, 1/3, 1/2)
5	Fairly Important	(4,5,6)	(1/6, 1/5, 1/4)
7	Strongly Important	(6,7,8)	(1/8, 1/7, 1/6)
9	Absolutely Important	(9,9,9)	(1/9, 1/9, 1/9)

If there is more than one decision maker, the preference of each decision maker is calculated using the geometric mean. According to the Buckley method (Buckley 1985), the geometric mean of fuzzy comparison values for each factor is calculated as shown in this equation below.

$$\tilde{d}_{ij} = \left(\prod_{j=1}^{k} \tilde{d}_{ij}^{k}\right)^{\frac{1}{k}}, i = 1, 2, \ldots, n \quad \text{… formula 3.5}$$

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij}\right)^{\frac{1}{n}}, i = 1, 2, \ldots, n \quad \text{… formula 3.6}$$

The fuzzy weight of each factor can be found by equation below.

$$\widetilde{w}_i = \tilde{r}_i \; x \; (\tilde{r}_1 + \tilde{r}_2 + \cdots + \tilde{r}_n) = (lw_i, mw_i, uw_i) \quad \text{… formula 3.7}$$

Because the result is still a triangular fuzzy number, it is necessary to defuzzify it, using the Center of Area method proposed by Chou and Chang, through equation below.

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \quad \text{… formula 3.8}$$

In fuzzy form, Saaty's approach in determining the level of inconsistency cannot be applied, so we need to calculate more than one value for each pairwise comparison matrix. Fuzzy matrix calculation uses two consistency ratios, namely CR_m (Consistency of Mean Value) and CR_g (Consistency of Lower and Upper Limits).

$$CI^m = \frac{(\lambda_{max}^m - n)}{(n-1)} \quad \text{… formula 3.9}$$

$$CI^g = \frac{(\lambda_{max}^g - n)}{(n-1)} \quad \text{… formula 3.10}$$

$$CR = \frac{CI}{RI} \quad \text{… formula 3.11}$$

The results of the weighting are called consistent if the two consistency ratios, namely CR_m and CR_g are less than 0.1 (Saaty 1986). If CR_m and CR_g of a certain pairwise comparison matrix is greater than 0.1, then the decision maker is advised to evaluate his preference value. If only CR_m and CR_g are greater than 0.1, while others are within the acceptable range, then decision makers are advised to re-evaluate the average value (extreme value) by keeping the extreme values (average value) does not change.

3.3 TOPSIS

After getting the weight on each criterion and sub-criteria, we can rank the alternatives based on the actual data we have. There are several steps that can be taken to use the TOPSIS method. We need to transforming the decision making matrix (x) into a normalized matrix (r) using Euclidean norms.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}} \quad \text{… formula 3.12}$$

The weighted normalized matrix (v) can be calculated with this equation below.

$$v_{ij} = r_{ij} \ x \ w_j \quad \text{… formula 3.13}$$

Furthermore, we can determine a positive ideal solution (v*) which will have a positive value for benefit criteria and a negative value for cost criteria and a negative ideal solution (v-) which will have a positive value for benefit criteria and a negative value for benefit criteria. Then, we can calculate the Euclidean distance between each alternative with positive and negative ideal solutions.

$$D_i^* = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^*\right)^2} \ \ i = 1, 2, \dots, m \quad \text{… formula 3.14}$$

$$D_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2} \ \ i = 1, 2, \dots, m \quad \text{… formula 3.15}$$

In the end, we can rank the alternatives by calculating the relative closeness for each alternative and determine the order of preference.

$$C_i^* = \frac{D_i^-}{D_i^* + D_i^-} \quad \text{… formula 3.16}$$

4. Data Collection

The criteria were obtained based on the literature review related to solar panel selection. There are total of 5 criteria, including electrical, mechanical, economic, environment, and customer satisfaction. Based on validation result from expert assessment, electrical criteria has 15 validated sub-criteria, mechanical criteria has 2 validated sub-criteria, economic criteria has 2 validated sub-criteria, environment criteria has 5 validated sub-criteria, and customer satisfaction has 3 validated sub-criteria. The Table 3 below represents a list of criteria and sub-criteria used in this research.

Table 3. Numerical Scales and Fuzzy Linguistics

Criteria	Code	Sub-Criteria
Electrical	E1	Maximum Power / P_{MAX} (Wp)
	E2	Max Power Voltage / V_{mp} (V)
	E3	Max Power Current / I_{mp} (A)
	E4	Temp Coeff of Isc (%/ºC)
	E5	Temp Coeff of Voc (%/ºC)
	E6	Temp Coeff of Pmax (%/ºC)
	E7	Operational Temperature (ºC)
	E8	Standard Test Condition / STC (W/m^2)
	E9	Open Circuit Voltage / Voc (V)
	E10	Short Circuit Current / Isc (A)
	E11	Maximum Series Fuse Rating (A)
	E12	Nominal Operating Cell Temperature / NOCT (ºC)
	E13	Power Tolerance (%)
	E14	Maximum System Voltage (V)
	E15	Module Efficiency (%)
Mechanical	M1	Weight (Kg)
	M2	Dimension (mm^3)
Economic	EC1	Price
	EC2	Cost per Watt

Environment	EN1	QSE Certification
	EN2	Protection Class Junction Box
	EN3	Max Load in (Pa)
	EN4	Area (m^2)
	EN5	Material (Poly/Mono)
Customer Satisfaction	CS1	Reliability
	CS2	Spare Parts Availability
	CS3	Service Support

After calculating the criteria using Fuzzy AHP method, we can get local weight and global weight for each sub-criteria. Based on the global weight values obtained from the calculations, Figure 1 below shows that the calculation results for the global weight values for each sub-criteria were obtained with Cost per Watt as the sub-criteria that had the highest level of importance, namely 0.119. Meanwhile, the Maximum Series Fuse Rating (A) sub-criteria is the sub-criteria with the lowest global weight value of 0.008.

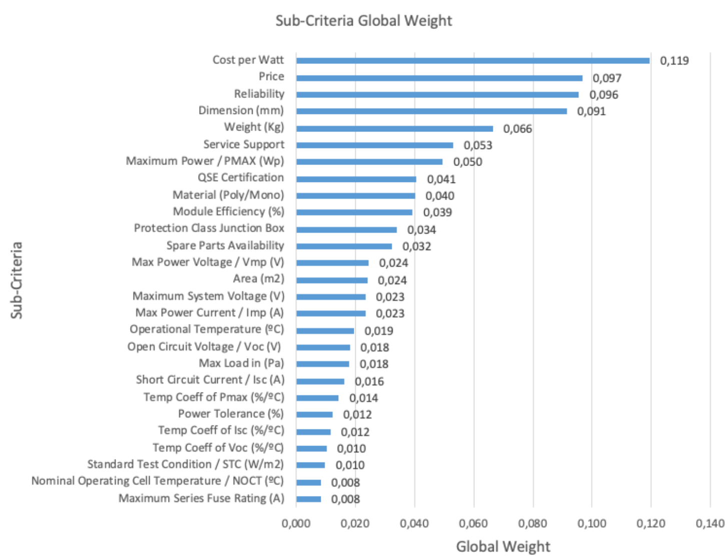

Figure 1. Sub-Criteria Global Weight

5. Results and Discussion

After successfully obtaining the global weight for each sub-criteria, we can enter the sub-criteria's actual value for each of the alternatives tested. The actual sub-criteria values related to technical matters, such as those categorized as electrical, mechanical, and environmental criteria, can be obtained from the product description, which is usually found on the technical data sheet for each product. As for the sub-criteria that are categorized in the economic and customer satisfaction criteria, they can be obtained from the market and business conditions owned by each product brand. For example, the author obtains actual price comparisons by conducting research on market prices given by sellers for each product. In finding customer satisfaction, the actual value of the reliability sub-criteria is obtained from the annual module capacity (MW/year) owned by each brand, then the spare parts availability sub-criteria is obtained from the inventory level rank of each company, while the service support sub-criteria can be obtained from the number of branches owned by each brand. The summary results of the actual value possessed by each alternative can be seen in the following Table 4.

Table 4. Actual Data Each Alternatives for Sub-Criteria

Code	Units	Alt. A	Alt. B	Alt. C	Alt. D	Alt. E	Alt. F	Alt. G	Alt. H	Alt. I
E1	Wp	540	540	540	540	540	540	540	540	540
E2	V	41,65	31,2	41,01	41,64	41	41,99	41,2	41,75	41,93

E3	A	12,97	17,33	13,17	12,97	13,18	12,88	13,11	12,94	12,88
E4	%/ºC	0,048	0,04	0,048	0,045	0,05	0,045	0,043	0,05	0,045
E5	%/ºC	-0,27	-0,25	-0,28	-0,275	-0,27	-0,27	-0,26	-0,26	-0,27
E6	%/ºC	-0,35	-0,34	-0,35	-0,35	-0,35	-0,35	-0,36	-0,34	-0,35
E7	ºC	125	125	125	125	125	125	125	125	125
E8	W/m^2	1	1	1	1	1	1	1	1	1
E9	V	49,5	37,5	49,53	49,6	49,2	49,6	49,4	49,54	49,9
E10	A	13,85	18,41	13,85	13,86	13,9	13,73	13,87	13,89	13,66
E11	A	25	30	25	25	25	25	25	25	30
E12	ºC	45	43	45	45	45	44	43	42	41
E13	%	5	5	3	5	10	3	3	5	5
E14	V	1500	1500	1500	1500	1500	1500	1500	1500	1500
E15	%	21,1	20,7	21,35	20,9	21,01	20,8	20,7	20,9	21,1
M1	Kg	27,2	28,6	28,9	28,6	29	32,5	32	32	32,3
M2	mm^3	89461680	91450240	88508700	90453510	89540150	77837760	91367500	77497560	89461680
EC1	$	140,4	113,4	135	151,2	140,4	124,2	113,4	124,2	113,4
EC2	$/W	0,26	0,21	0,25	0,28	0,26	0,23	0,21	0,23	0,21
EN1	No of Certificates	3	3	3	3	3	3	3	3	3
EN2	IP68	1	1	1	1	1	1	1	1	1
EN3	Pa	5400	5400	5400	3600	5400	5400	5400	5400	5400
EN4	m^2	2556,048	2612,864	2528,82	2584,386	2558,29	2594,592	2610,5	2583,252	2556,048
EN5	Module Type	1	1	1	1	1	1	1	1	1
CS1	MW/Year	50000	33600	31000	23200	16100	14100	10000	10000	8000
CS2	Inventory Level	1	1	1	1	1	1	1	1	1
CS3	No of Branches	3	3	3	3	2	0	0	1	1

By incorporating the weight considerations that have been obtained from previous data processing into the actual value of the sub-criteria, we can get the most optimal ranking of alternatives. In Table 5, it can be seen that alternative A is ranked first with a preference value of 0.829. The preference value tends to have quite a difference from the second rank, namely alternative B with a preference value of 0.671, which is then followed by the third rank, namely alternative C with a preference value of 0.602.

Table 5. Alternatives Ranking

Alternatives	**Preference *C****	**Ranking**
Alt. A	0,829	1
Alt. B	0,671	2
Alt. C	0,602	3
Alt. D	0,459	4
Alt. E	0,309	5
Alt. F	0,230	7
Alt. G	0,227	8
Alt. H	0,226	9
Alt. I	0,244	6

6. Conclusion

In selecting the type of solar panel based on the brand, which is carried out using Fuzzy AHP-TOPSIS, the subjectivity obtained from the decision maker is reduced, ensuring ambiguity and various inaccuracies when evaluating are eliminated. This method succeeded in providing the most optimal solar panel product recommendations by considering the main criteria that are often used when selecting solar panels, namely electrical, mechanical, economic, environmental, and customer satisfaction criteria. Based on the data processing carried out on the assessment of experts, it appears that the electrical criteria have the most weight, followed sequentially by economic, customer satisfaction, mechanical, and environmental criteria. However, when viewed from the global weight value of each sub-criteria, the 5 sub-criteria that have the highest weight sequentially are the sub-criteria cost per watt, price, reliability, dimension, and weight. Based on the weight values obtained, we can get the most optimal solar panel product overall, which is alternative A. Meanwhile, the least recommended solar panel product overall is alternative H.

References

Ahmetovic, H., Nukic, E., Hivziefendic, J., Saric, M., and Ponjavic, M., PV system site selection using PVGIS and Fuzzy AHP, *2022 21st International Symposium INFOTEH-JAHORINA, INFOTEH 2022 - Proceedings*, 2022. https://doi.org/10.1109/INFOTEH53737.2022.9751261

Almanasreh, E., Moles, R., and Chen, T. F., Evaluation of methods used for estimating content validity, *Research in Social & Administrative Pharmacy : RSAP*, vol. 15, no. 2, pp. 214–221, 2019. https://doi.org/10.1016/J.SAPHARM.2018.03.066

Balo, F., and Şağbanşua, L., The Selection of the Best Solar Panel for the Photovoltaic System Design by Using AHP, *Energy Procedia*, vol. 100, pp. 50–53, 2019. https://doi.org/10.1016/J.EGYPRO.2016.10.151

Bouzid, M., Elleuch, M. A., and Frikha, A., Multi-criteria and multi-decision maker ranking of photovoltaic panels in Tunisia, *2021 International Conference on Decision Aid Sciences and Application,* pp. 932–937, 2021. https://doi.org/10.1109/DASA53625.2021.9682287

Buckley, J. J., Fuzzy hierarchical analysis. *Fuzzy Sets and Systems*, vol. 17, no. 3, pp. 233–247, 1985. https://doi.org/10.1016/0165-0114(85)90090-9

Direktorat Jenderal Ketenagalistrikan Kementerian Energi dan Sumber Daya Mineral, Buletin Ketenagalistrikan Edisi 61 Volume XVI, Available: https://dev.sidak.bantenprov.go.id/view-pdf/1, Accessed on October 10, 2022.

Fleiss, J. L, *Statistical methods for rates and proportions*, 2nd Edition, Wiley, 1981.

Global Solar Atlas, Available: https://globalsolaratlas.info/download/indonesia, Accessed on October 10, 2022.

Kementerian Lingkungan Hidup dan Kehutanan Direktorat Jenderal Pengendalian Perubahan Iklim, Statistik Tahun 2018 Direktorat Jenderal Pengendalian Perubahan Iklim, Available: https://ditjenppi.menlhk.go.id/reddplus/images/adminppi/dokumen/statistik_PPI_2018_opt.pdf, Accessed on October 10, 2022.

Kusumawardani, R. P., and Agintiara, M., Application of Fuzzy AHP-TOPSIS Method for Decision Making in Human Resource Manager Selection Process, *Procedia Computer Science*, vol. *72*, pp. 638–646, 2015. https://doi.org/10.1016/J.PROCS.2015.12.173

Lynn, M. R., Determination and quantification of content validity, *Nursing Research*, vol. *35*, no. 6, pp. 382–386, 1986. https://doi.org/10.1097/00006199-198611000-00017

Polit, D. F., and Beck, C. T., The content validity index: are you sure you know what's being reported? Critique and recommendations, *Research in Nursing & Health*, vol. 29, no. 5, pp. 489–497, 2006. https://doi.org/10.1002/NUR.20147

Polit, D. F., Beck, C. T., and Owen, S. V., Is the CVI an acceptable indicator of content validity? Appraisal and recommendations, *Research in Nursing & Health*, vol. 30, no. 4, pp. 459–467, 2007. https://doi.org/10.1002/NUR.20199

Prajapati, S., Upadhyay, Y., Chharia, A., and Sharma, B, A novel hybrid Fuzzy AHP-TOPSIS Approach towards Enhanced multi-criteria Feature-based EV Recommender System, *2021 2nd Global Conference for Advancement in Technology, GCAT 2021*, October 1, 2021. https://doi.org/10.1109/GCAT52182.2021.9587713

Presiden Republik Indonesia, Undang Undang Republik Indonesia Nomor 16 Tahun 2016 tentang Pengesahan Paris Agreement To The United Nations Framework Convention On Climate Change (Persetujuan Paris Atas

Konvensi Kerangka Kerja Perserikatan Bangsa-Bangsa mengenai Perubahan Iklim), Available: https://peraturan.bpk.go.id/Home/Details/37573, Accessed on October 10, 2022.

Presiden Republlik Indonesia, Peraturan Presiden Republik Indonesia Nomor 22 Tahun 2017 tentang Rencana Umum Energi Nasional, Available: https://jdih.esdm.go.id/peraturan/Perpres%2022%20Tahun%202017.pdf, Accessed on October 10, 2022.

Saputra, G, Harnessing Indonesia's Solar Potential: Yellow is The New Black – IESR, Available: https://iesr.or.id/harnessing-indonesias-solar-potential-yellow-is-the-new-black, Accessed on October 10, 2022.

Setiawan, A. D., Hidayatno, A., Putra, B. D., and Rahman, I., Selection of Charging Station Technology to Support the Adoption of Electric Vehicles in Indonesia with the AHP-TOPSIS Method, *2020 3rd International Conference on Power and Energy Applications, ICPEA 2020*, pp. 85–88, 2020. https://doi.org/10.1109/ICPEA49807.2020.9280125

Shrotryia, V. K., and Dhanda, U., Content Validity of Assessment Instrument for Employee Engagement, *SAGE Open*, vol. 9, no. 1, 2019. https://doi.org/10.1177/2158244018821751

United Nations Climate Change, *Nationally Determined Contributions Registry*, Available: https://unfccc.int/NDCREG, Accessed on October 10, 2022.

Waltz, C. Feher., Strickland, Ora., Lenz, E. R., and Waltz, C. Feher. (2005), *Measurement in nursing and health research,* 3rd Edition*,* Springer Pub, 2005.

Yang, B., Sun, Y., and Lin, Y., Decision-making on PV modules for very large scale photovoltaic systems using improved analytic hierarchy process, *Asia-Pacific Power and Energy Engineering Conference, APPEEC*, 2011. https://doi.org/10.1109/APPEEC.2011.5748582

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