



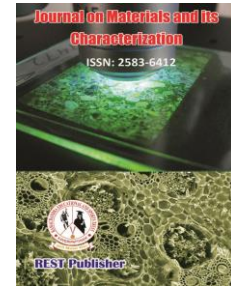
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A Decision-Support Framework for Photovoltaic Technology Selection Based on the ARAS Method

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Abstract: Solar cells, often known as photovoltaic (PV) cells, are mechanically inert systems that use light to produce energy. Electricity can be produced by some PV cells using artificial light. Sunlight is made up of photons, or solar energy particles. The primary focus of this essay is the fight over standards for photovoltaic technology systems. There are now five commercially accessible photovoltaic technologies, and it is unclear which one will become the most popular. We create and assess technological superiority categories and criteria for these systems based on the literature and expert interviews. We assess the significance of these elements and the probability that one of these five technologies will take over as the primary photovoltaic technology using an analytical hierarchy process. The data is analyzed using Agile and the ARAS Analytical Hierarchical Process Methodology. According to the findings, pricing strategy and technological superiority are the two aspects that have the most influence on the dominance process, making sustained support strategy the most significant type. Furthermore, first-generation technology has the highest chance of achieving mono-crystalline silicon PV dominance. Numerous parties that must choose which standard to support for photovoltaic technology will find the study's findings useful.

Keywords: This keyword represents the composite material system under study, consisting of short glass fibers embedded in an epoxy resin matrix. SGFRE composites are widely used in automotive, aerospace, and structural applications due to their favorable balance of strength, stiffness, weight, and cost.

1. INTRODUCTION

Governments, decision-makers in the energy sector, academics, companies that make electricity, etc. are increasingly placing a high priority on renewable energy technologies in an effort to guarantee universal access to electricity, Increase the amount of renewable energy used to generate electricity globally, make home appliances more energy efficient, and ultimately open up new opportunities that could result in sustainable development. How photovoltaic (PV) technology work and what does is it? PV technology involves the conversion of solar energy into electrical energy through the use of PV materials and equipment. A photovoltaic cell, which is the fundamental unit of PV technology, is relatively small and typically generates 1 to 2 watts of power. These cells are incredibly thin, even thinner than four human hairs, and are made from various semiconductor materials. To protect them from the elements, the cells are enclosed between protective layers of glass and/or plastics. To increase their power output, PV cells are interconnected in larger groups called modules or panels. These modules can be used individually or combined in arrays for more substantial electricity generation. To form a comprehensive PV system, one or more arrays are then connected to the electrical grid. Thanks to their modular design, PV systems can be tailored to meet various electric power requirements, making them adaptable for different needs. In recent years, solar electricity systems have become increasingly popular worldwide, both for on-grid and off-grid applications, primarily due to the continuous decline in PV module prices. Due to this development, the 1.2 billion people worldwide who have no access to a contemporary energy supply are now thought of as having a potential alternative for obtaining electricity from PV systems; it is alarming to remember that about half of these individuals reside in sub-Saharan Africa [3]. In a PV system, the modules and arrays are just one part of the overall setup. The system consists of various components working together to ensure its proper functioning. These components are responsible for converting the direct current (DC) electricity generated by the panels into the alternating current (AC) electrical power used to operate all the electrical appliances in a home. Additionally, there are mounting frames designed to orient the panels towards the sun for optimal solar energy capture. These components collectively form a complete PV system that harnesses solar energy efficiently and

supplies electricity for residential or commercial use. The choosing of technology should take into account a number of factors that have been extensively researched. A sustainable evaluation approach that incorporates technological, economic, environmental, and social categories is presented, building on the triple bottom line [12, 13]. The urgent need for developing renewable energy has been made clear by the frightening rate at which fossil resources like coal, oil, and natural gas are being depleted. By the end of 2019, it is anticipated that renewable energy sources will generate more than 26% of the world's total electricity [1]. Solar energy is regarded as one of the most powerful and effective sources of renewable energy [2, 3]. Photovoltaic (PV) technologies can be used to refer to any technology that includes converting solar radiation into electricity [4, 5]. Commercially, there are five primary PV technologies, each utilizing different production methods and materials:

- Single-crystalline cells (SC-Si)
- Multi-crystalline cells (mc-Si)
- Amorphous silicon (a-Si)
- Cadmium telluride (CDTE)
- Copper indium (gallium) selenide (CI(G)S)

These technologies are widely employed in the solar energy industry [6, 7, 8, 9]. To build a low-carbon civilization, one must choose a sustainable dominant PV technology [10]. While there are publications on selecting technologies, the majority of them only consider economic and technological aspects, ignoring the influence of social and environmental issues [2, 11]. Additionally, In the conventional technology selection process, the multi-criteria decision making (MCDM) method is commonly employed. However, this approach poses challenges in determining precise preferences due to the involvement of subjective and ambiguous linguistic judgments throughout the selection process. To address the uncertainty arising from the information used in the selection process, fuzzy set theory is integrated with MCDM. This integration allows for a more effective handling of uncertainty, leading to improved decision-making outcomes. However, the MCDM based on fuzzy set theory has two significant flaws: the need for a lot of prior knowledge and the inability to handle subjectivity. While new-generation (film-type) photovoltaic technology has not achieved widespread adoption yet, it holds promising prospects for the future. This innovative technology boasts several advantages, such as low unit cost, versatility in applications, and a wide absorption waveband range, making it suitable for diverse product interfaces. As a result, major global solar manufacturers like Sharp, Q-Cells, Sanyo, and Schott Solar have started taking an interest in this technology among others. As it continues to garner attention from prominent industry players, the potential for its growth and implementation is quite optimistic. Large manufacturers have consequently started investing in and developing film technology in a variety of ways. Only minimal amounts of silicon or other metallic components are needed to make this form of solar cell, and it can be done continuously. As a result, raw material costs are often minimal. The thickness of solar cells can be significantly reduced thanks to film technology, and The thickness of contemporary a-Si film products is only about 0.5 m. Additionally, compared to traditional silicon solar cells, the power loss of film-type photovoltaic cells is smaller than that of exposed portions, making them better suitable for power generation in low-light conditions. Light transmission, power-temperature coefficients, and cumulative power generation are all appropriate for film-type products. Additionally, when made as series batteries, a built-in connection component is present in film-type solar cells to prevent internal short circuits. Because of their exceptionally thin profile and high light transmittance, these cells find practical applications in building-integrated photovoltaics (BIPVs). Film-type solar cells come in a wide variety of new varieties, and their applications go beyond power generation systems. Given their relatively inexpensive raw materials, film-type solar cells present an appealing alternative for Taiwanese companies looking to venture into the photovoltaic industry.

2. MATERIALS AND METHOD

PV (photovoltaic) technology is indeed a viable and sustainable renewable energy option, primarily due to two key factors. First, the sun provides an endless and abundant supply of solar radiation, ensuring a constant source of energy. Second, PV cells have the unique ability to directly convert this solar radiation into electricity, making them highly efficient in harnessing solar energy for electricity generation. The scientific community and governments have been very interested in this technology ever since the first efficient photovoltaic cell was developed in the 1950s. During the 1970s, the oil shocks and subsequent rise in oil prices served as catalysts, incentivizing research and development (R&D) efforts and market penetration for PV technology. Today, there are five PV technology concepts that are actively being explored and commercially developed. These various designs are competing against each other for market dominance, resulting in what economists and managers often refer to as "standards battles" or "platform wars" [1]. This competitive landscape is driving innovation and progress in the field of photovoltaics, leading to advancements in solar energy adoption and implementation. PV technology assessment is conducted using the ARAS (Additive Ratio Assessment) method to determine the effectiveness of a novel approach. The assessment involves

evaluating ten key factors: Adaptability, Technological advancement, Power conversion efficiency of PV cells (PCE), Cost of PV manufacturing, Durability of PV supply, Resource constraints and pollution, Effects on human health, Government support, financial incentives and Job creation. Currently, there are five commercially available types of PV technology: Single-crystalline cells (SC-Si), Multi-crystalline cells (mc-Si), Amorphous silicon (a-Si), Cadmium telluride (CDTE), and Copper indium (gallium) selenide (CI(G)S). The ARAS method allows for a comprehensive evaluation of these PV technologies, considering their potential impact on various critical aspects and aiding in decision-making for the most suitable technology adoption. The first two are classified as photovoltaic cells made of crystalline silicon, whereas the latter three are thin film photovoltaic cells. Single-crystalline cells (sc-Si) and multi-crystalline cells (mc-Si) both belong to the category of crystalline silicon photovoltaic cells. On the other hand, amorphous silicon (a-Si), cadmium telluride (CDTE), and copper indium (gallium) selenide (CI(G)S) are part of the thin-film photovoltaic cell category. These distinctions are based on the materials and manufacturing processes used to create the different types of photovoltaic cells. Using a framework already established in the literature [5], we created a list of criteria that affect the choice of technology during the first stage. To identify the factors that are important for the PV market, we then conducted three expert interviews. In the second stage of the study, the analytical hierarchy method (AHP) was employed to develop a questionnaire. This questionnaire aimed to explore the significance of various factors influencing decision-making among companies operating along the PV value chain. The AHP allowed for the prioritization of these factors based on their relative importance. To assess the relative importance of these variables, two approaches were used: the crisp approach and the ARAS approach. The crisp approach involves precise and definitive values, whereas the ARAS approach incorporates the Additive Ratio Assessment to consider uncertainties and vagueness in the decision-making process. By utilizing both methods, the study could gain a comprehensive understanding of how these factors impact the decision-making process of companies in the PV industry. As part of the research process, six semi-structured interviews were conducted to foster mutual understanding with the experts. During these interviews, the criterion list was thoroughly reviewed and validated for accuracy by consulting with the experts. This iterative approach ensured that the criteria used for the analytical hierarchy method (AHP) and the ARAS approach were comprehensive, relevant, and aligned with the insights and knowledge provided by the experts. The double-checking process helped enhance the reliability and validity of the research findings, providing a robust foundation for the study's outcomes. In order to reduce the impact of several measurement units and optimization directions in MADM, Zavadskas and Turskis⁴ originally introduced the ARAS approach. The process is broken down into five key steps: In Step 1, the decision-making matrix is generated to aid in the decision-making process. The matrix presents crucial information about each alternative concerning each attribute under consideration. By filling in the matrix, a comprehensive comparison of the alternatives becomes possible, facilitating a clearer understanding of their strengths and weaknesses across the various criteria. There are m alternatives, n attributes, n columns and $m + 1$ rows show the ideal value for each attribute. Normalizing the initial data is step two. Absolutely, normalizing the data in the decision-making matrix is a crucial step to ensure that subsequent computations and comparisons are valid and meaningful. Since the data for each alternative might be measured in different units or scales, normalization helps to bring them to a common scale, making them directly comparable. There are various methods for normalizing data, and the most common one is to scale the data to fall within a specific range, often between 0 and 1. This is usually done using formulas like min-max normalization or z-score normalization. In Step 3, after normalizing the decision-making matrix as discussed in Step 2, the next step is to define the normalized weighted matrix. The weights (W_j) for each characteristic (attribute) are determined in this stage. These weights reflect the relative importance or significance of each attribute in the decision-making process. The process of assigning weights involves gathering input from experts, stakeholders, or decision-makers who can provide insights into the importance of each attribute. These weights are typically represented as numerical values between 0 and 1, with higher values indicating greater importance. Once the weights are assigned, they are used to calculate the weighted sum of each alternative's normalized values across all attributes. This results in a weighted matrix that takes into account both the relative importance of each attribute and the performance of each alternative concerning those attributes. The normalized weighted matrix is a crucial step in various decision-making methods, such as the analytical hierarchy process (AHP) or the Additive Ratio Assessment (ARAS), as it helps in determining the overall ranking and identifying the most suitable alternative based on the specified criteria. This weight shows the relative relevance of the various attributes. Step 4: Determine the utility degree values and the optimality function we may get the optimality function value for each option after creating the normalized weighted decision-making matrix. In Step 5, after completing the necessary calculations and assessments, the outcomes are rated based on the utility values. The higher the utility value, the more favorable the alternative is considered. By ranking all the alternatives from best to worst based on their degree of utility, the most favorable options are identified. Throughout the decision-making process using methods like the analytical hierarchy process (AHP) or the Additive Ratio Assessment (ARAS), the utility values are computed, taking into account the normalized data and the assigned weights for each attribute. These values reflect the overall performance of each alternative relative to the specified criteria. The ranking of alternatives based on their utility values provides a clear understanding of which options best align with the objectives and priorities of the decision-makers. This helps in making informed choices and selecting the most suitable alternative for the given decision problem.

TABLE 1. Alternative

Financial strength of the agent	A1
Brand reputation and credibility	A2
Operational supremacy	A3
Flexibility	A4
Appropriability strategy	A5
Timing of entry	A6
Marketing communications	A7
Pre-emption of scarce assets	A8
Commitment	A9
Diversity of the network	A10

In the context of a competitive business environment, the success and long-term viability of a company are heavily influenced by a variety of factors. A list of additional elements that affect an agent's overall power and effectiveness is provided in Table 1. Firstly, financial strength (A1) is a vital consideration as it enables an agent to invest in growth opportunities, weather economic uncertainties, and support innovation. Secondly, brand reputation and credibility (A2) significantly influence customer trust and loyalty, enhancing the agent's market position. Operational supremacy (A3) reflects the ability to deliver products or services efficiently, ensuring customer satisfaction and cost-effectiveness. Flexibility (A4) is essential in adapting to dynamic market conditions, enabling timely responses and the exploration of new opportunities. Appropriability strategy (A5) relates to the agent's ability to protect its intellectual property and secure a competitive advantage. The timing of entry (A6) in a market can be critical for establishing a foothold and gaining a competitive edge. Effective marketing communications (A7) help to create brand awareness, attract customers, and build strong relationships. Pre-emption of scarce assets (A8) involves securing limited resources or strategic assets ahead of competitors, ensuring long-term viability. Commitment (A9) to goals and strategies contributes to consistency and perseverance in achieving desired outcomes. Lastly, the diversity of the network (A10) allows access to a broad range of resources, expertise, and opportunities. Overall, the combination and effective management of these factors can significantly impact an agent's success and competitive advantage in the marketplace.

3. RESULT AND DISCUSSION

TABLE 2. Data set

	sc-Si	mc-Si	CI(G)S	CdTe	a-Si
A1	39.7	39.7	6.4	10.6	3.5
A2	34.2	34.2	13	13	5.6
A3	47.7	31.4	4.9	4.9	11.1
A4	33.3	33.3	11.1	11.1	11.1
A5	35.7	35.7	2.9	16.2	9.6
A6	35.3	35.3	5.4	8.7	15.2
A7	36	36	3	16.5	8.6
A8	39.3	39.3	3.3	6.2	12
A9	20	20	20	20	20
A10	36.7	36.7	4.6	4.6	17.3

Table 2 provides a data set comparing different solar cell technologies: SC-Si, mc-Si, CI(G)S, CDTE, and a-Si, across various factors denoted as A1 to A10. Analyzing the data, we can observe variations in performance and characteristics among the technologies. For instance, these scores provide valuable insights into the relative performance and characteristics of each solar cell technology, aiding in the assessment and decision-making processes for adopting or investing in these technologies.

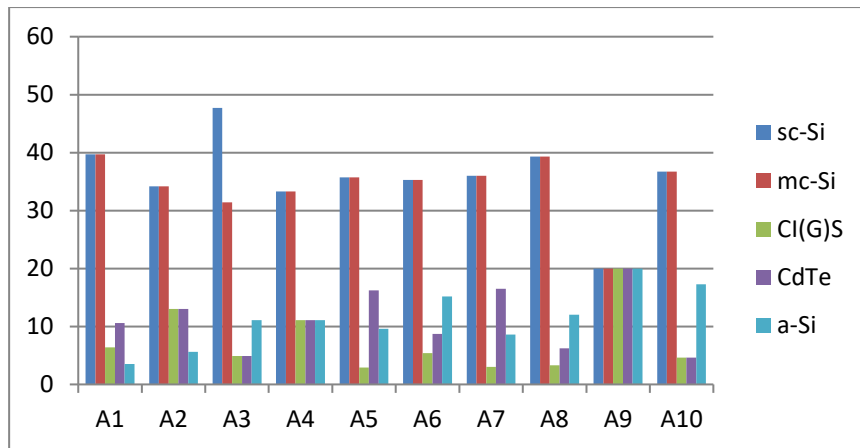


FIGURE 1. Data set

Figure 1 shows that the Data set SC-Si and mc-Si consistently score high across most factors, indicating their strong financial strength (A1) and brand reputation (A2). On the other hand, CI (G) S demonstrates comparatively lower scores for financial strength (A1) and operational supremacy (A3), but excels in appropriability strategy (A5). CDTE exhibits significant strengths in flexibility (A4) and marketing communications (A7), while a-Si stands out in factors like appropriability strategy (A5), timing of entry (A6), and diversity of the network (A10).

TABLE 3. Identify maximum values

	sc-Si	mc-Si	CI(G)S	CdTe	a-Si
Max	47.7	39.7	20	20	20
A1	39.7	39.7	6.4	10.6	3.5
A2	34.2	34.2	13	13	5.6
A3	47.7	31.4	4.9	4.9	11.1
A4	33.3	33.3	11.1	11.1	11.1
A5	35.7	35.7	2.9	16.2	9.6
A6	35.3	35.3	5.4	8.7	15.2
A7	36	36	3	16.5	8.6
A8	39.3	39.3	3.3	6.2	12
A9	20	20	20	20	20
A10	36.7	36.7	4.6	4.6	17.3

In Table 3, the maximum values for each technology across the factors are as follows: c-Si: 47.7 (maximum value in A3), mc-Si: 39.7 (maximum value in A1), CI (G) S: 20 (maximum value in A9), CDTE: 20 (maximum value in A9) and a-Si: 20 (maximum value in A9). These maximum values represent the highest scores or performance achieved by each solar cell technology across the listed factors. They indicate the strengths or advantages that each technology possesses in specific areas.

TABLE 4. Normalized Matrix

	sc-Si	mc-Si	CI(G)S	CdTe	a-Si
Max	0.117604	0.104117	0.211416	0.151745	0.149254
A1	0.09788	0.104117	0.067653	0.080425	0.026119
A2	0.08432	0.089693	0.137421	0.098634	0.041791
A3	0.117604	0.08235	0.051797	0.037178	0.082836
A4	0.082101	0.087333	0.117336	0.084219	0.082836
A5	0.088018	0.093627	0.030655	0.122914	0.071642
A6	0.087032	0.092578	0.057082	0.066009	0.113433
A7	0.088757	0.094414	0.031712	0.12519	0.064179
A8	0.096893	0.103068	0.034884	0.047041	0.089552
A9	0.04931	0.052452	0.211416	0.151745	0.149254

Table 4 presents a normalized matrix for the solar cell technologies: SC-Si, mc-Si, CI(G)S, CDTE, and a-Si. The values in the matrix are normalized using the maximum values obtained from Table 3. The maximum normalized values for each technology across the factors are as follows: SC-Si: 0.117604 (maximum normalized value in A3), mc-Si: 0.104117 (maximum normalized value in A1), CI(G)S: 0.211416 (maximum normalized value in A3), CDTE: 0.151745 (maximum normalized value in A3) and a-Si: 0.149254 (maximum normalized value in A3) These

normalized values provide a relative comparison of each technology's performance across the different factors. By normalizing the values, we can assess the strengths and weaknesses of each technology in a standardized manner, taking into account their maximum potential across the factors.

TABLE 5. Weighted

	sc-Si	mc-Si	CI(G)S	CdTe	a-Si
A1	0.2	0.2	0.2	0.2	0.2
A2	0.2	0.2	0.2	0.2	0.2
A3	0.2	0.2	0.2	0.2	0.2
A4	0.2	0.2	0.2	0.2	0.2
A5	0.2	0.2	0.2	0.2	0.2
A6	0.2	0.2	0.2	0.2	0.2
A7	0.2	0.2	0.2	0.2	0.2
A8	0.2	0.2	0.2	0.2	0.2
A9	0.2	0.2	0.2	0.2	0.2
A10	0.2	0.2	0.2	0.2	0.2

Table 5 presents a weighted matrix where each factor (A1 to A10) is assigned a weight of 0.2 for each solar cell technology: SC-Si, mc-Si, CI(G)S, CDTE, and a-Si. The weighted matrix signifies that each factor is considered equally important in the evaluation process. By assigning the same weight (0.2) to all factors, a balanced approach is taken to assess the technologies. This equal weighting implies that no specific factor is given more significance over others when evaluating the performance or characteristics of the solar cell technologies. Each factor contributes equally to the overall assessment. Analyzing the weighted matrix, we can conclude that all the factors, regardless of their unique characteristics, are considered equally vital for evaluating the technologies.

TABLE 6. Weighted Normalized Matrix

	sc-Si	mc-Si	CI(G)S	CdTe	a-Si
Max	0.023521	0.020823	0.042283	0.030349	0.029851
A1	0.019576	0.020823	0.013531	0.016085	0.005224
A2	0.016864	0.017939	0.027484	0.019727	0.008358
A3	0.023521	0.01647	0.010359	0.007436	0.016567
A4	0.01642	0.017467	0.023467	0.016844	0.016567
A5	0.017604	0.018725	0.006131	0.024583	0.014328
A6	0.017406	0.018516	0.011416	0.013202	0.022687
A7	0.017751	0.018883	0.006342	0.025038	0.012836
A8	0.019379	0.020614	0.006977	0.009408	0.01791
A9	0.009862	0.01049	0.042283	0.030349	0.029851
A10	0.018097	0.01925	0.009725	0.00698	0.025821

Table 6 represents a weighted normalized matrix for the solar cell technologies: SC-Si, mc-Si, CI(G)S, CDTE, and a-Si. The values in the matrix are both weighted and normalized based on the weights from Table 5 and the maximum values from Table 4. The maximum weighted normalized values for each technology across the factors are as follows: SC-Si: 0.023521 (maximum weighted normalized value in A3), mc-Si: 0.020823 (maximum weighted normalized value in A1), CI(G)S: 0.042283 (maximum weighted normalized value in A3), CDTE: 0.030349 (maximum weighted normalized value in A3) and a-Si: 0.029851 (maximum weighted normalized value in A3). In the weighted normalized matrix, the values are normalized to provide a relative comparison of each technology's performance across the factors, considering the assigned weights. By combining normalization and weighting, we can assess the strengths and weaknesses of each technology while taking into account the importance of each factor. The weighted normalized matrix allows for a comprehensive evaluation, considering both the relative performance across factors and the assigned weights to those factors. This evaluation provides insights into the performance of each solar cell technology, taking into consideration the factors that are considered most important in the assessment process.

TABLE 7. Si and Ki

	Si	Ki
Max	0.146827	1
A1	0.075239	0.512432
A2	0.090372	0.615497
A3	0.074353	0.506396
A4	0.090765	0.618174
A5	0.081371	0.554196
A6	0.083227	0.566835
A7	0.080851	0.55065
A8	0.074288	0.505954
A9	0.122835	0.836598
A10	0.079873	0.543992

Table 7 provides the values of Si and Ki for a set of factors (A1 to A10). Si represents the overall score for each factor, while Ki represents the overall score for each solar cell technology. The maximum values for Si and Ki are as follows: Si values are 0.146827 (maximum value in Max) and Ki values are 1 (maximum value in Max). These scores provide a quantitative representation of the performance and contribution of each factor and technology. Si represents the relative importance or contribution of each factor, while Ki represents the overall performance or strength of each technology, taking into account the scores of the factors. The Si and Ki scores allow for a comprehensive evaluation and comparison of the factors and technologies, considering their respective contributions and performances. These scores can assist in decision-making processes, such as selecting the most suitable technology based on the weighted factors or identifying areas of improvement for the factors.

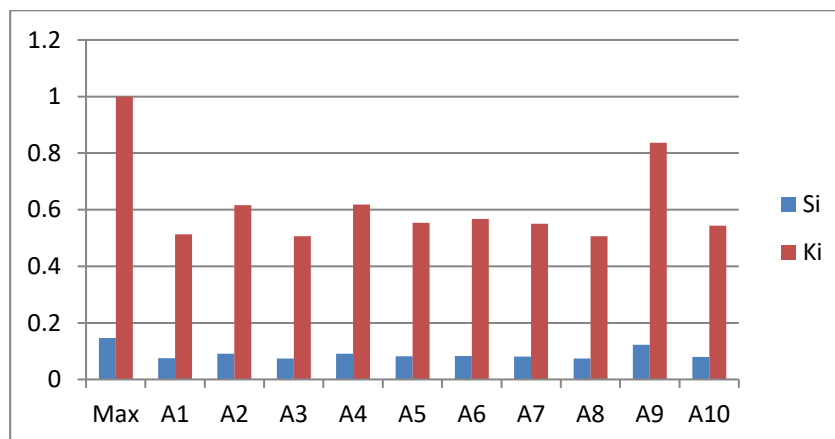


FIGURE 2. Si and Ki values

Analyzing the values in figure 2, we can observe the scores for Si and Ki for each factor and technology. For example, factor A1 has a Si score of 0.075239 and contributes to a Ki score of 0.512432 for the technologies. Similarly, the other factors contribute to the overall Si and Ki scores for each technology.

TABLE 8. Ranking

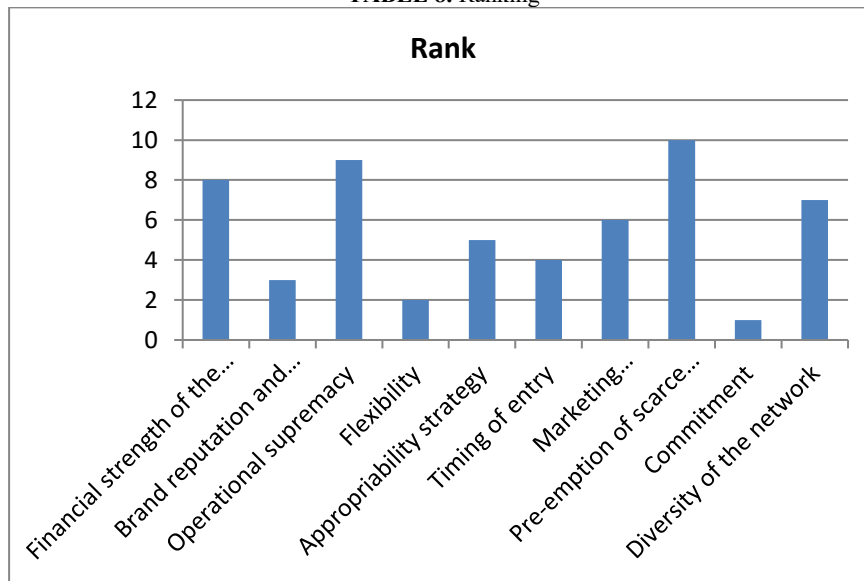


FIGURE 3. Ranking

According to the rankings, Commitment is deemed the most important factor, receiving the top ranking. Flexibility follows closely in the second rank, Brand reputation and credibility are ranked third, emphasizing the value of a strong reputation and customer trust. Timing of entry is ranked fourth, Appropriability strategy is ranked fifth, Marketing communications are ranked sixth, Diversity of the network is ranked seventh, financial strength of the agent is ranked eighth, Operational supremacy is ranked ninth, and Pre-emption of scarce assets is ranked tenth.

4. CONCLUSION

In this article, the foundation of the research is built upon various sources, including frameworks from earlier studies, market observations, and insights gathered from interviews with business leaders from different sectors related to photovoltaic (PV) technology. These sectors include PV manufacturers, research facilities, academic institutions, and solar panel installation companies. The study focused on two main aspects: standard dominance and technological designs. Thirteen elements were considered to assess standard dominance, while five different technological designs were evaluated using the sharp ARAS method. By integrating knowledge from previous studies, real-world market observations, and inputs from industry experts, this research aims to provide a comprehensive and robust analysis of the PV industry's current state and future trends. The ARAS method was employed to facilitate decision-making and provide valuable insights into standard dominance and the potential of different technological designs in the PV sector. The study's findings reveal that pricing strategy and technological superiority play significant roles in the dominance process within the PV industry, exerting the most influence. Conversely, appropriability strategy and financial strength have a relatively lesser impact on the dominance of PV technologies. Moreover, the research demonstrates that single-crystalline cells (sc-Si) have the highest likelihood of surpassing other PV technologies in terms of market dominance. The study's contributions to the existing literature are multifaceted. Firstly, it sheds light on the critical factors that shape the competitive landscape within the PV industry, providing valuable insights for business leaders and decision-makers in the sector. Secondly, it offers a comprehensive analysis of different PV technologies, enabling stakeholders to make more informed choices in terms of investments and strategic decisions. Thirdly, the research highlights the importance of pricing strategies and technological advancements in gaining a competitive edge, which can be utilized as a guide for formulating effective market strategies. Additionally, the study identifies the potential for sc-Si to lead the market, which can help guide research and development efforts and resource allocation within the industry. Overall, this research contributes significantly to the body of knowledge in the PV domain, offering practical implications and insights for various stakeholders involved in the solar energy sector. They can gain greater knowledge about the elements that are crucial and lessen the uncertainty surrounding their investments in standardization. The practitioner can interview a group of experts from inside its institution to properly implement the suggested procedure, and any discrepancies in judgements should be reviewed with the goal of arriving at a single overall judgment for each pairwise comparison. To choose the sustainable PV technology, an integrated MCDM technique is created. When choosing PV technology, social and environmental factors are taken into account. With cloud model theory, the

randomness in technological decision-making is addressed. In order to manipulate problems with tiny sample sizes, the grey relational analysis method is applied.

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