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Review article

Analysis of solar module alternatives for efficiency-based energy investments with hybrid 2-tuple IVIF modeling

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ABSTRACT

The purpose of this study is to examine optimal solar module investments. Firstly, key determinants of the performance of solar energy investments are evaluated by DEMATEL method with the 2-tuple IVIF sets. Moreover, the cell material alternatives for solar module investments are also ranked. For this purpose, an evaluation has been made by 2-tuple IVIF TOPSIS. The contributions of the paper are performing a priority analysis to understand the most significant factors to increase solar energy projects and creating an original model by the integration of DEMATEL and TOPSIS with the 2-tuple IVIF sets. The findings denote that crystalline silicon is the optimal solar panel module to increase the performance of these projects. In the short term, government subsidies can provide cost advantages to solar energy investors. It is not a very continuous practice to try to increase these projects only with government supports. The costs of solar energy projects should be reduced to solve this problem permanently. Owing to new technological developments, high cost problem of solar energy investments can be handled more successfully.

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1. Introduction

Solar energy projects benefit countries in many ways. Since only sunlight is used in the electricity generation process, it does not harm the environment. This situation makes a very serious contribution to reducing the environmental pollution problem that occurs in the electricity production process. Air pollution resulting from carbon emissions is the main source of many important problems such as global warming. In this context, solar panels are very important for countries with the clean energy they produce (Noor et al., 2022). Solar energy projects also provide energy independence of countries. Countries that do not have fossil resources within their borders should import energy. The economy becomes fragile as it will adversely affect the current account balance. Energy independence can be provided even if they do not have fossil resources (Abderrazak et al., 2022).

Despite these benefits, the high investment costs are essential problem for these projects. This situation negatively affects the profitability of the projects. Therefore, investors may also be reluctant to invest in solar panels. Solving this problem is vital for clean energy production (Kareri et al., 2022). Moreover, the fact that the amount of energy produced is not continuous is another disadvantage of solar energy projects. Since sunlight is needed to generate electricity from these panels, there is a significant decrease in the amount of electricity produced in the evening. This situation causes irregularities in the amount of electricity produced. Similarly, the amount of energy obtained during the peak hours of the sun is also very high (Hassan et al., 2022). If this amount is more than the required energy, some of the produced energy is lost. Therefore, the solution of this problem is very important for the energy produced from solar panels to be efficient.

In summary, it is necessary to take some actions to solve the problems of solar energy projects. For the efficiency of these panels to be high, they must be installed in the right location. In this context, areas with intense sunlight are needed. The presence of other energy sources in the country also affects the performance of these projects (Xue et al., 2022). Countries that are strong in other types of energy may not prefer to progress in solar energy projects. The supports given by governments are also very important. In this context, the fact that states do not collect taxes from solar energy investors will provide these projects with a significant competitive advantage (Verduci et al., 2022). In addition, lowering the interest rates of the loans given by the government for solar energy investments will also contribute to reducing the costs of these projects.

Some market-based factors also affect the performance of solar energy investments. For example, in a market with high costs, the profitability of solar energy investments may be low. In this context, uncertainties in the market will increase during periods of high inflation. Therefore, it is seen that markets with stable inflation rates are more suitable for solar energy investments (Inada et al., 2022). Furthermore, the energy demand in the market is another phenomenon that should be taken into consideration when deciding on solar energy investments. Investing in solar energy in a market where there is not enough demand will adversely affect performance (Salimi et al., 2022). Effective financial markets in the country are also essential on the effectiveness of solar energy projects (Kang et al., 2022). In advanced financial markets, innovative financial products are more likely to be developed. This will help solar energy projects to find financial support more easily.

Which of the solar panels to invest in is another issue that needs to be answered. There are different types of solar panels. For example, some solar panels can use amorphous silicon. Various non-crystalline silicones such as glass, metal and plastic are preferred in these panels (Stuckelberger et al., 2017). Therefore, these panels are considered environmentally friendly. On the other hand, low efficiencies compared to other panels is considered as one of the most important disadvantages of amorphous silicones. Monocrystalline solar panels are one of the oldest and most well-known types of solar panels. These panels consist of a single crystal structure. One of the biggest advantages of monocrystalline solar panels is that they have the highest efficiency rate. Since the solar cell consists of a single crystal, electrons have more spaces to move. This makes monocrystalline panels more efficient (Taşçıoğlu et al., 2016). A transparent mechanism is used in organic solar panels. These transparent solar panels, which consist of organic salts, have photovoltaic glasses and with their help, sunlight is converted into electricity. The most important advantages of organic solar panels are that they are cheap to produce and that the harm to the environment is minimal. Their lower efficiency is also considered to be the most important disadvantage of organic solar panels (Van Quyen and Duc, 2022).

Many different issues need to be examined to determine the most suitable solar panels for investment. The important issue here is which issues should be given priority in these investments. Both policy makers and investors have specific budgets. As a result of simultaneous improvement studies for many factors, there is a risk that the costs will increase too much. With these costs reaching an uncontrollable level, it will be difficult for the projects to be sustainable in the long run. Therefore, it is essential to conduct a priority analysis for the influencing factors of solar energy projects. On the other hand, according to this priority analysis to be made, it is necessary to determine the most suitable solar panels for investment (Nguyen et al., 2022; Phan et al., 2021; Tran and Duong, 2019).

The aim of this study is to examine optimal solar module investments. First of all, key determinants of the performance of solar energy investments are evaluated by DEMATEL method with the 2-tuple IVIF sets. Secondly, the cell material alternatives for solar module investments are also ranked.

Accordingly, this manuscript tries to find optimal solar module investments. For this purpose, a new decision-making model has been established. In the first stage, the factors that affect the performance of solar energy investments are examined. A priority analysis has been performed with the help of DEMATEL method with the 2-tuple IVIF sets. The next part of the model ranks the cell material alternatives for solar module investments. Within this framework, an evaluation has been made by the extension of TOPSIS approach with the 2-tuple IVIF sets.

The main contributions are implemented in detailed calculation process of the paper are as follows:

(i) A priority analysis has been performed so that it can be possible to understand the most significant factors to increase solar energy investments. The results of the analysis to be obtained will especially guide policy makers. In this way, it will be possible to increase these projects with the implementation of effective policies. Thus, it will be easier for countries to increase their use of clean energy and to achieve independence in energy.

(ii) The ranking results give information about the most optimal solar module for the investment decision. Therefore, the listing of the relevant alternatives will be especially helpful for investors. Investors will be able to reach an efficient investment decision more easily in this complex process by taking into consideration the results of this analysis.

(iii) Considering DEMATEL technique to find the most essential influencing factors of solar energy investment is another superiority of this study. In the literature, there are different types of decision-making techniques. Nonetheless, the main difference of DEMATEL is that it is also possible to make impact-relation analysis regarding the criteria (Bhuiyan et al., 2022a; Sun et al., 2022). The main determinants of solar energy investments can have an impact on each other. As an example, the government supports can also have a positive influence on the cost effectiveness. Thus, DEMATEL is an optimal approach while making examination about the factors of solar energy investments.

(iv) Selecting TOPSIS to rank cell material alternatives for solar module investments is another advantage of the proposed model. Both negative and positive optimal solutions are used in the analysis (Bhuiyan et al., 2022a; Kayacık et al., 2022). Finding the most optimal solar panel type is a critical analysis. These results will have an impact on the decisions of investors who will make very high investments. In this context, considering the TOPSIS method, which exhibits a more sensitive approach in the analysis process, increases the quality of the examination to be made.

(v) Finally, considering the 2-tuple linguistic evaluation and IVIF sets also provides some advantages. It can be possible to minimize the information loss in the evaluation process. Hence, it can be possible to increase the coherency of the examinations (Zhao et al., 2022).

The following part includes the examination of the literature with respect to solar energy investments. Methodology is taken place in the next section. Analysis results are presented in the fourth section. Discussions, recommendations and conclusions are -given finally.

2. Literature review

Due to its many vital benefits to countries, solar energy investments have been frequently discussed in the literature, especially in recent years. In a significant part of the studies, the factors affecting the increase of solar energy investments were discussed. The location where solar panels will be installed is one of the most discussed issues in this process. To obtain high efficiency from solar energy, the panels must be installed in the appropriate area (Jagoda et al., 2022). During the installation of the panels, it is necessary to choose the places that can receive the most sunlight (Sudharshan et al., 2022). Thus, more sunlight will be benefited, and this will contribute to the increase of electrical energy obtained from solar panels (Gutiérrez et al., 2022). In other words, there is a risk of decreasing solar energy investments as a result of installing solar panels in the wrong location (Lipovšek et al., 2022). Thanh and Lan (2022) defined that selection of the location is a critical factor. Narayanamoorthy et al. (2022) also focused on this subject for different country groups. They reached a conclusion that optimal solar power plant location should be identified firstly for the performance improvement of these projects.

Government subsidies are another issue that has a positive effect on the performance of these projects (Sung et al., 2022). On the other hand, the high investment costs are one of the biggest negative aspects of these projects. This situation causes solar energy investments to lose their competitiveness (Liang et al., 2022; Rathore and Panwar, 2022). Investors will not prefer solar panels because the high cost will cause a decrease in profitability (Montoya-Duque et al., 2022). In this process, the financial support provided by the state contributes to the minimization of this disadvantage. Xu et al. (2022) concluded that tax incentives have a positive impact on the solar energy investors because it provides a cost advantage. Alzahrany et al. (2022) also underlined the significance of low-interest loans to be offered to solar energy investors by governments.

The energy demand in the country also affects the performance of solar energy investments. The demand for energy in the country to be invested should be analyzed (Mertens, 2022). In this process, the population density of the country should be taken into consideration (Perez and Perez, 2022). Since the demand for energy will be high in countries with a large population, the probability of success of solar energy projects increases much more (Salimi et al., 2022). Otherwise, in countries where there is not enough demand for energy, it will be difficult to sell the electricity produced from solar panels (Hossain, 2022). This will lead to a decrease in the success of the projects. Abu-Hamdeh et al. (2022) focused on the ways to improve the performance of solar energy projects. They stated that customer demands for energy consumption play a crucial role. Eslami et al. (2022) made a study for the solar energy investment effectiveness in Turkey. It is concluded that energy demand in the country should be understood clearly for this purpose (Li et al., 2021; Wang et al., 2019; Li et al., 2022; Saqib et al., 2021; Bhuiyan et al., 2022b).

The technological competence of enterprises is also effective on the performance of solar energy projects. For solar panels to be successful, costs must be reduced. To achieve this goal, businesses need to actively follow up-to-date technology (Kassem and Abdalla, 2022). Thanks to the timely application of these technologies, the costs of these projects can be decreased (Martínez-Sánchez et al., 2022). A budget should be provided for research and development studies (Serag and Echchelh, 2022; Oktik, 2022). Carbajo and Cabeza (2022) demonstrated that for the performance improvements of these projects, technological development plays a crucial role. Similarly, Papamichael et al. (2022) discussed that companies should mainly make investments for technology improvements.

The literature review shows that solar panels are very important for the country's economy. In this context, the factors affecting the performance of these projects were emphasized throughout the studies. Nevertheless, there are limited studies that make a priority analysis for these influencing factors. There is a risk of having too much costs while making improvements for all factors at the same time. When these costs reach an uncontrollable level, it will be difficult for the projects to be sustainable in the long run. It is necessary to determine the criteria that are more important for investors in the selection of the most suitable solar module. Thus, it will be possible to determine more accurate investment strategies. Accordingly, this manuscript tries to find optimal solar module investments with a new decision-making model.

3. Methodology

This study aims to find optimal solar module investments. Within this scope, a model is established with the extension of DEMATEL and TOPSIS approaches with the 2-tuple IVIF sets. The details of these techniques are explained in this section.

The calculation process has the levels of analysis of solar module alternatives for efficiency-based energy investments with hybrid 2-tuple IVIF modeling. However, firstly, evaluation of the effectiveness of energy investments indifferent countries with continental shelf and determined the significance levels of criteria for efficiency indicators. Secondly, the importance of distribution, political stability, and technological capacity for energy investment effectiveness. Thirdly, making recommendations for the countries to pay attention to political stability and improve technological infrastructure.

3.1. 2-tuple IVIF sets

In the process of determining the best one among different alternatives, various factors have started to be effective. As a result, it became very difficult to reach the right decision. In this context, decision making methods have been tried to be strengthened with different actions. Considering fuzzy numbers in the calculations using these methods is one of these important steps. Herrera and Martínez (2000) introduced the 2-tuple linguistic model for this purpose. Hence, the main purpose is to illustrate computing with words. With the help of this issue, evaluations of the experts can be examined more effectively. Similarly, Atanassov (1986) generated IVIF sets by extending the classical fuzzy numbers. In this context, the limits of belongingness and non-belongingness are provided for the elements. Owing to this situation, the vague sets with the limited numbers can be obtained in the evaluation process. In this study, the 2-tuple linguistic model is integrated with IVIF sets. $S = \{s_0, \ldots, s_g\}$ demonstrates the linguistic terms and $\langle S \rangle = S \times [-0.5, 0.5)$ is used for 2-tuple linguistic information. $\Delta\colon [0, g] \rightarrow \langle S \rangle$ can be presented as in Eqs. (1) and (2). In this equation, β gives information about the round term. Bijective function is shown by Δ, $i \in \{0, \ldots, g\}$ refers tp the integer number.

$$\Delta(\beta) = (S_i, \alpha), \; with \begin{cases} i = round(\beta) \\ \alpha = \beta - i \end{cases} \tag{1}$$

$$\Delta^{-1}\colon \langle S \rangle \rightarrow [0, g] \text{ and } \Delta^{-1}(S_i, \alpha) = i + \alpha \tag{2}$$

Eq. (3) indicates the details of IFS (I) in which $\mu_I(\vartheta)/n_I(\vartheta)$ refers to the belongingness/non-belongingness degrees. The sum of them should be between 0 and 1.

$$I = \{\langle \vartheta, \mu_I(\vartheta), n_I(\vartheta) \rangle / \vartheta \epsilon U\} \tag{3}$$

The details of these sets based on upper and lower values are shown in Eqs. (4) and (5). In this scope, $\mu_{IU}(\vartheta)/\ \mu_{IL}(\vartheta)$ demonstrates upper/lower values $\mu_I(\vartheta)$. Similarly, the upper/lower values of $n_I(\vartheta)$ are stated by $n_{IU}(\vartheta)/\ n_{IL}(\vartheta)$.

$$I = \{\vartheta, [\mu_{IL}(\vartheta), \mu_{IU}(\vartheta)], [n_{IL}(\vartheta), n_{IU}(\vartheta)] / \vartheta \epsilon U\} \tag{4}$$

$$0 \le \mu_{IU}(\vartheta) + n_{IU}(\vartheta) \le 1 \mu_{IL}(\vartheta) \ge 0, n_{IL}(\vartheta) \ge 0 \tag{5}$$

Unknown degree is given in Eq. (6).

$$\tau_I(\vartheta) = 1 - \mu_I(\vartheta) - n_I(\vartheta) \tag{6}$$

The elements of I are explain in Eq. (7) where a, b, c, d denote the terms of $\mu_{IL}(\vartheta)$, $\mu_{IU}(\vartheta)$, $n_{IL}(\vartheta)$, $n_{IU}(\vartheta)$.

$$I = ([a, b], [c, d]) \tag{7}$$

3.2. DEMATEL

There can be many different factors affecting an issue. However, in some cases it may be important to determine the most important of these factors. DEMATEL is also a method used for this purpose (Fang et al., 2021). DEMATEL is integrated by the 2-tuple IVIF sets. First, optimistic (MSTC) and pessimistic (PSTC) values can be defined as in Eq. (8) (Liu et al., 2021).

$$\tilde{Z}_{ij} = \left(\left(a_{ij}, b_{ij}\right), \left(c_{ij}, d_{ij}\right)\right) \tag{8}$$

The accuracy function $A(i) \in [0, 1]$ is explained in the next step with Eq. (9).

$$A(i) = \frac{a_{ij} + b_{ij} + c_{ij} + d_{ij}}{2} \tag{9}$$

Eq. (10) is used to establish relation matrix (A).

$$A_k = \begin{bmatrix} 0 & \cdots & a_{1nk} \\ \vdots & \ddots & \vdots \\ a_{n1k} & \cdots & 0 \end{bmatrix} \tag{10}$$

Normalized values are computed as in Eq. (11).

$$B = \left[b_{ij}\right]_{nxn} = \frac{A}{max \sum_{j=1}^{n} a_{ij}} \tag{11}$$

Eq. (12) is considered to create total relation matrix (C).

$$C = \left[c_{ij}\right]_{nxn} = B(I - B)^{-1} \tag{12}$$

Eqs. (13) and (14) are used to compute D and E that denote the sum of the rows and columns. By using them, both the causal directions and the weights can be identified.

$$D = \left[d_{ij}\right]_{nx1} = \left[\sum_{j=1}^{n} c_{ij_{ij}}\right]_{nx1} \tag{13}$$

$$E = \left[e_{ij}\right]_{1xn} = \left[\sum_{j=1}^{n} c_{ij_{ij}}\right]_{1xn} \tag{14}$$

3.3. TOPSIS

TOPSIS is used in this study to compare solar module investment alternatives. With this method, it is possible to determine the most optimal alternative. In this proposed model, TOPSIS is extended with the 2-tuple IVIF sets. In the first step, the opinions of the experts are collected (Dong et al., 2022). Secondly, decision matrix (D) is created by Eqs. (15) and (16). The defuzzified values are given with h_{ij} (Cheng et al., 2020).

$$D = \begin{matrix} \\ A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_m \end{matrix} \begin{matrix} \begin{matrix} C1 & C2 & C3 & \ldots & Cn \end{matrix} \\ \begin{bmatrix} h_{11} & h_{12} & h_{13} & \cdots & h_{1n} \\ h_{21} & h_{22} & h_{23} & \cdots & h_{2n} \\ h_{31} & h_{32} & h_{33} & \cdots & h_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ h_{m1} & h_{m2} & h_{m3} & \cdots & h_{mn} \end{bmatrix} \end{matrix} \tag{15}$$

$$h_{ij} = \frac{1}{k}\left[\sum_{e=1}^{n} h_{ij}{}^{e}\right] \tag{16}$$

Thirdly, (A^+) and (A^-) are computed by Eqs. (17) and (18).

$$A^+ = \max(v_1, v_2, v_3, \ldots, v_n) \tag{17}$$

$$A^- = \min(v_1, v_2, v_3, \ldots, v_n) \tag{18}$$

Eqs. (19)–(21) are considered to identify closeness coefficient (CC_i).

$$D_i{}^+ = \sqrt{\sum_{i=1}^{m} (v_i - A_i{}^+)^2} \tag{19}$$

$$D_i{}^- = \sqrt{\sum_{i=1}^{m} (v_i - A_i{}^-)^2} \tag{20}$$

$$CC_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{21}$$

4. Analysis results

The analysis results are presented in three different sub parts.

Phase 1: Determine key issues solar module investment decision.

Optimal solar module investments are evaluated. Firstly, significant determinants of solar energy investments are defined as in Table 1.

There are two different dimensions that are operational and market-based. As for operational dimension, location plays a key role. In this context, there is a strong need for the availability of free space for these investments. Governmental policies are also

Table 1
Determinants of solar energy investments.

Groups	Factors	References
Operational	Governmental policies	Narayanamoorthy et al. (2022)
	Location	Eslami et al. (2022)
	Alternative energy sources	Mertens (2022)
Market-based	Cost	Martínez-Sánchez et al. (2022)
	Demand	Anh et al. (2021)
	Financial facilities	Alzahrany et al. (2022)

Table 2
Cell material alternatives for solar module investments.
Source: National Renewable Energy Laboratory, Solar Module Efficiency Guide, https://www.nrel.gov/pv/assets/pdfs/solar-module-efficiency-data-guide.pdf.

Alternatives
Amorphous Silicon
Chalcogenide
Dye-Sensitized
Hybrid
III-V
Organic Photovoltaic
Perovskite
Crystalline Silicon

Table 3
Linguistic evaluations for criteria, dimensions, and alternatives.

Criteria	Alternatives	Values
no (n)	very bad (W)	1
some (s)	bad (BD)	2
normal (m)	normal (NL)	3
important (h)	successful (UEC)	4
crucial (vh)	wonderful (DRF)	5

Table 4
Weights for dimensions.

	Operational	Market-based	Weights
Operational	3.00	4.00	.500
Market-based	3.00	3.00	.500

necessary for this situation. Incentives for commercial and individual users can attract the attention of the investors. Availability of other renewable and non-renewable energies is also another significant issue for solar energy investment decisions. Initial and maintain costs of solar energy panels should be taken into consideration. Similarly, the changes of consumption and peak demand should also be satisfied. Finally, necessary financial programs such as leasing and third-part ownership should be available. Additionally, eight different solar module investment types are defined by considering "Solar Module Efficiency Guide" created by National Renewable Energy Laboratory. These alternatives are defined in Table 2.

While evaluating these factors, the values in Table 3 are used.

Phase 2: Weight the dimensions and criteria of solar energy investments with 2-tuple IVIF DEMATEL

The expert team is made up of three different people (RTTA). They have more than 26 years of experience in solar energy investment projects. Similarly, they work as top managers in international solar energy companies. In the analysis process, firstly, the weights of the dimensions are defined. Boundaries of the linguistic term sets (Table A.1), 2-tuple values (Table A.2) and IVIF sets (Table A.3) are computed. In the following steps, direct relation matrix (Table A.4) and normalized matrix (Table A.5) are generated. Next, total relation matrix is created. Table 4 explains thee weights.

It is concluded that both operational and market-based dimensions have equal weights. After that, similar calculations are made for the criteria under these dimensions separately. With respect to the criteria under the operational dimension, boundaries of the linguistic term sets (Table A.6), 2-tuple values (Table A.7) and IVIF sets (Table A.8) are established. In the following steps, direct relation matrix (Table A.9) and normalized matrix (Table A.10) are created. The weights of these determinants are shown in Table 5.

Table 5
Weights of operational factors.

	Weights
Governmental policies	.351
Location	.340
Alternative energy sources	.308

Table 6
Weights of market-based factors.

	Weights
Cost	.322
Demand	.338
Financial facilities	.339

Table 7
Weighting results.

Dimensions	Weights	Criteria	Local weights	Global weights
Operational	0.50	Governmental policies	.351	.176
		Location	.340	.170
		Alternative energy sources	.308	.154
Market-based	0.50	Cost	.322	.161
		Demand	.338	.169
		Financial facilities	.339	.170

Table 8
Module sizes for solar energy investments.

Sizes	Area cm^2
Mini module	200–800
Small module	800–6500
Standard module	6500–14000
Large module	14000

Table 9
Ranking and weighting results of module sizes for solar energy investments.

Sizes	D+	D-	CCi	Ranking	Weighting
Mini module	.200	.035	.148	4	.064
Small module	.154	.081	.344	3	.148
Standard module	.040	.194	.828	2	.357
Large module	.000	.234	1.000	1	.431

The findings indicate that the governmental policies play the most critical role under operational dimension. Boundaries (Table A.11), 2-tuple values (Table A.12) and IVIF sets (Table A.13) are identified. Later, direct relation matrix (Table A.14) and normalized matrix (Table A.15) are constructed. Table 6 gives information about the weights of these items.

It is identified that financial facilities have the greatest weight under the market-based dimension. After that, the global weights are computed by considering all criteria together. The weighting results are demonstrated in Table 7.

It is defined that governmental policies have the highest importance for solar energy investment projects. Location and financial facilities are also significant. Hence, for the improvements of these projects, necessary actions should be taken primarily by governments. In this context, tax incentives and financial support by the governments have a strong influence on the cost effectiveness of these projects.

Table 10
Recent efficiency results of solar module alternatives by Sizes (percentage).
Source: National Renewable Energy Laboratory, Champion Photovoltaic Module Efficiency, https://www.nrel.gov/pv/module-efficiency.html

Alternatives/ Modul Sizes (Area cm^2)	Mini module (200–800 cm^2)	Small module (800–6500 cm^2)	Standard module (6500–14000 cm^2)	Large module (higher than 14000 cm^2)
Amorphous Silicon	–	10.4	–	12.3
Chalcogenide	16.6	19.2	17.4	19
Dye-Sensitized	8.8	–	–	-
Hybrid	40.6	–	–	-
III-V	–	25.1	33.5	-
Organic Photovoltaic	11.7	8.7	–	-
Perovskite	17.3	16.1	–	-
Crystalline Silicon	21.1	15.5	24.4	20.4

Note: The most recent measurement dates are considered to illustrate the efficiencies of solar modules.

Table 11
Weighted decision matrix for solar module alternatives.

Alternatives/ Module Sizes (Area cm^2)	Mini module (200–800 cm^2)	Small module (800-6500 cm^2)	Standard module (6500-14000 cm^2)	Large module (higher than 14000 cm^2)
Amorphous Silicon	.000	.038	.000	.174
Chalcogenide	.020	.070	.138	.269
Dye-Sensitized	.010	.000	.000	.000
Hybrid	.048	.000	.000	.000
III-V	.000	.091	.266	.000
Organic Photovoltaic	.014	.031	.000	.000
Perovskite	.021	.058	.000	.000
Crystalline Silicon	.025	.056	.194	.289

Table 12
Ranking results of solar module alternatives.

Alternatives	D+	D-	CCi	Ranking
Amorphous Silicon	.298	.178	.374	4
Chalcogenide	.134	.311	.698	2
Dye-Sensitized	.405	.010	.025	8
Hybrid	.403	.048	.107	6
III-V	.293	.281	.490	3
Organic Photovoltaic	.398	.034	.079	7
Perovskite	.395	.062	.135	5
Crystalline Silicon	.083	.353	.809	1

Phase 3: Measure the module sizes with respect to the determinants of solar energy investments with 2-tuple IVIF TOPSIS

The third phase includes the measurement of the module sizes for solar energy investments. The sizes and areas in Table 8 are used in the analysis process.

Boundaries (Table A.16), 2-tuple values (Table A.17), IVIF sets (Table A.18) and defuzzified values (Table A.19) are constructed. Table 9 identifies the ranking results of the module sizes.

Table 9 states that the large module is the optimal one for solar energy investments. Standard module is also another critical size. Nonetheless, mini and small modules are in the last ranks.

Phase 4: Rank the cell material alternatives of solar energy investments with TOPSIS

The efficiency values of solar module alternatives with respect to module sizes are considered for ranking the cell material alternatives of solar energy investments. For this purpose, the procedures of TOPSIS method are applied to measure the performance of solar module alternatives. The results in Table 10 are defined as a decision matrix.

However, the weighting results from phase 3 are used for obtaining the weighted decision matrix. The weighted decision matrix is presented in Table 11.

The ranking results of phase 4 are given in Table 12.

Table 12 denotes that crystalline silicon is the optimal solar panel module. Chalcogenide and III-V also play an essential role for this purpose. Organic photovoltaic and Dye-Sensitized take place in the last ranks.

Table A.1
Boundaries for dimensions.

	Operational			Market-based		
	RTTA 1	RTTA 2	RTTA 3	RTTA 1	RTTA 2	RTTA 3
Operational				$[s, vh]$	$[m, h]$	$[s, h]$
Market-based	$[m, h]$	$[n, h]$	$[s, h]$			

Table A.2
2-tuple values.

	Operational		Market-based	
	MSTC	PSTC	MSTC	PSTC
Operational			(h,.33)	(s,.33)
Market-based	(h,0)	(s,0)		

5. Discussions

The installation cost of solar panels is quite high. This situation makes investors nervous as it will negatively affect profitability. In addition, the amount of electricity generated from solar panels varies considerably throughout the day. In this context, the amount of electricity produced increases during the hours when the sun is high. On the other hand, a much lower amount of electricity is obtained in the evening. Instability in electricity generation is one of the most important disadvantages of solar panels.

Although the solar energy project is very important for the country's economy, the cost-related disadvantages in these projects prevent them from increasing their investments. Therefore, for the development of these projects, this high-cost negativity needs to be eliminated. For this purpose, it is necessary to increase government support. Until these projects gain a financial advantage, meeting this high-cost problem with government support is one of the most important solutions. Tax reductions to be provided by the government will create cost advantages for these projects. In addition, the financial support to be given to these

Table A.3
IVIFSs for the dimensions.

	Operational	Market-based
Operational		((.60,.67), (.20,.27))
Market-based	((.40,.60), (.10,.20))	

Table A.4
Direct relation matrix for dimensions.

	Operational	Market-based
Operational	.00	.87
Market-based	.65	.00

Table A.5
Normalized marix.

	Operational	Market-based
Operational	.00	1.00
Market-based	.75	.00

investors by the states will contribute positively to increasing the profitability of the projects. Arias-Gaviria et al. (2019) aimed to evaluate solar energy projects in Colombia. They discussed that the key factor to improve the performance of these projects is government support. Within this framework, they pointed out that tax reductions play a crucial role. Martinopoulos and Tsalikis (2018) made also a similar examination for Greece. It is identified that governments should decrease the tax ratio for solar energy investments.

One of the issues necessary to increase solar energy projects is to invest in energy technologies. First, thanks to these developing technologies, it will be possible to reduce the costs of these projects in a long time. Moreover, thanks to the developing technologies, it is possible to store the excess energy produced at a lower cost. This situation can minimize the problem of instability in energy production in solar energy projects. Amankwah-Amoah (2015) made an evaluation of the solar energy market in sub-Saharan Africa. It is identified that for the long-term performance of solar energy projects to be sustainable, investment in energy technologies is required. Haschke et al. (2018) concluded that companies should give priority to energy technologies for the long-term performance increase of solar energy projects.

According to the results obtained in this study, it has been determined that crystalline solar panels are the most suitable investment type. One of the biggest advantages of crystal solar panels is that they have the highest efficiency rate. The most important reason for this is that they are made of high-grade silicone. In summary, crystalline silicons help to produce high energy even in much less sunlight. On the other hand, crystalline silicon solar panels are also important in terms of saving space. It is understood that these panels are a very good solution for long-term projects (Alwaelya et al., 2021; Dayong et al., 2020).

Results proved that there are different types of solar panels, and each type has its own advantages and disadvantages. Crystal solar panels are one of the most used types (Ji and Liu, 2018). The initial cost of these panels is higher than the others (Soltani et al., 2022). On the other hand, the efficiency of the projects increases due to the high amount of energy obtained (Lu et al., 2021). Furthermore, the popularity of organic panels has been increasing, especially in recent years (Anh et al., 2021). It is a very important advantage that the materials used in these panels do not harm the environment. On the other hand, the fact that the material used is transparent can keep the sun's rays less and this reduces efficiency (Tempesta et al., 2022). Amorphous silicons are also considered in solar panels. Since non-crystalline materials are used in these panels, the damage to the environment can be minimized (Myojo and Ohashi, 2018).

6. Policy recommendations

It is possible to propose both short-term and long-term policies to increase solar energy investments. In the short term, government support is vital. Today, the installation costs of solar panels are quite high compared to fossil fuels. Therefore, until this problem disappears, government subsidies will provide cost advantages to solar energy investors. On the other hand, it is not a very continuous practice to try to increase these projects only with state supports. In this context, to solve this problem permanently, the costs of solar energy projects should be reduced. In this context, it is important to increase investments in energy technologies. Thanks to new technological developments, it will be possible to reduce the costs of solar energy investments. Finally, considering today's conditions, it would be appropriate for investors to focus on crystalline solar panels. According to the analysis results obtained, crystalline solar panels are determined as the most efficient type.

7. Conclusions

In this study, it is aimed to identify optimal solar module investments. In this scope, a new model has been constructed. First, the determinants that affect the performance of solar panels are stated. Next, a priority analysis has been made with the help of DEMATEL method with the 2-tuple IVIF sets. Secondly, the cell

Table A.6
Boundaries of operational criteria.

	Governmental policies			Location			Alternative energy sources		
	RTTA 1	RTTA 2	RTTA 3	RTTA 1	RTTA 2	RTTA 3	RTTA 1	RTTA 2	RTTA 3
Governmental policies				$[h, vh]$	$[s, m]$	$[h, vh]$	$[s, vh]$	$[m, h]$	$[s, h]$
Location	$[m, vh]$	$[m, vh]$	$[s, h]$				$[m, h]$	$[m, vh]$	$[n, h]$
Alternative energy sources	$[s, m]$	$[s, h]$	$[m, h]$	$[s, m]$	$[n, m]$	$[s, h]$			

Table A.7
2-tuple values for operational group.

	Governmental policies		Location		Alternative energy sources	
	MSTC	PSTC	MSTC	PSTC	MSTC	PSTC
Governmental policies			(h,.33)	(m,.33)	(h,.33)	(s,.33)
Location	(h,.33)	(m,−.33)			(h,.33)	(s,.33)
Alternative energy sources	(h,−.33)	(s,.33)	(m,.33)	(n,−.33)		

Table A.8
IVIF sets.

	Governmental policies	Location	Alternative energy sources
Governmental policies		((.60,.67), (.40,.47))	((.60,.67), (.20,.27))
Location	((.60,.73), (.20,.33))		((.60,.67), (.20,.27))
Alternative energy sources	((.40,.53), (.20,.27))	((.40,.47), (.10,.13))	

Table A.9
DRM of operational group.

	Governmental policies	Location	Alternative energy sources
Governmental policies	.00	1.07	.87
Location	.93	.00	.87
Alternative energy sources	.70	.55	.00

Table A.10
NDR for operational group.

	Governmental policies	Location	Alternative energy sources
Governmental policies	.00	.55	.45
Location	.48	.00	.45
Alternative energy sources	.36	.28	.00

Table A.11
Boundaries of market-based factors.

	Cost			Demand			Financial facilities		
	RTTA 1	RTTA 2	RTTA 3	RTTA 1	RTTA 2	RTTA 3	RTTA 1	RTTA 2	RTTA 3
Cost				$[n, h]$	$[s, m]$	$[s, h]$	$[m, vh]$	$[m, h]$	$[s, h]$
Demand	$[m, vh]$	$[m, vh]$	$[h, vh]$				$[m, h]$	$[m, vh]$	$[m, vh]$
Financial facilities	$[m, vh]$	$[m, h]$	$[m, h]$	$[m, h]$	$[m, vh]$	$[s, vh]$			

Table A.12
2-tuple values for market-based group.

	Cost		Demand		Financial facilities	
	MSTC	PSTC	MSTC	PSTC	MSTC	PSTC
Cost			(h,−.33)	(n,−.33)	(h,0)	(m,−.33)
Demand	(vh,0)	(m,.33)			(vh,0)	(m,0)
Financial facilities	(h,.33)	(m,0)	(vh,−.33)	(m,−.33)		

Table A.13
IVIFSs for market-based factors.

	Cost	Demand	Financial facilities
Cost		((.40,.53), (.10,.13))	((.40,.60), (.20,.33))
Demand	((.60,.80), (.40,.47))		((.60,.80), (.20,.40))
Financial facilities	((.60,.67), (.20,.40))	((.60,.73), (.20,.33))	

Table A.14
DRM of market-based factors.

	Cost	Demand	Financial facilities
Cost	.00	.58	.77
Demand	1.13	.00	1.00
Financial facilities	.93	.93	.00

Table A.15
NDR for market-based group.

	Cost	Demand	Financial facilities
Cost	.00	.27	.36
Demand	.53	.00	.47
Financial facilities	.44	.44	.00

material alternatives for solar module investments are ranked. It is defined that governmental policies have the highest importance for solar energy investment projects. Crystalline silicon is the optimal solar panel module to increase the performance of solar energy investments.

The main contributions of the paper are performing a priority analysis to understand the most significant factors to increase solar energy projects and creating an original model by the integration of 2-tuple IVIF sets with DEMATEL and TOPSIS. The main limitation of this study is that a general assessment has been

Table A.16
Boundaries of linguistic term sets for solar energy investments.

	Governmental policies			Location			Alternative energy sources		
	RTTA 1	RTTA 2	RTTA 3	RTTA 1	RTTA 2	RTTA 3	RTTA 1	RTTA 2	RTTA 3
Mini module	[UEC, DRF]	[*BD*, UEC]	[NL, UEC]	[UEC, DRF]	[NL, UEC]	[UEC, DRF]	[UEC, DRF]	[*BD*, NL]	[NL, UEC]
Small module	[NL, UEC]	[NL, UEC]	[NL, UEC]	[NL, UEC]	[NL, UEC]	[UEC, DRF]	[NL, DRF]	[NL, UEC]	[UEC, DRF]
Standard module	[UEC, DRF]	[NL, UEC]	[NL, UEC]	[NL, UEC]	[UEC, DRF]	[UEC, DRF]	[UEC, UEC]	[NL, UEC]	[UEC, DRF]
Large module	[UEC, DRF]	[UEC, DRF]	[NL, DRF]	[NL, DRF]	[UEC, DRF]	[UEC, DRF]	[UEC, UEC]	[NL, UEC]	[UEC, DRF]
	Cost			**Demand**			**Financial facilities**		
	RTTA 1	**RTTA 2**	**RTTA 3**	**RTTA 1**	**RTTA 2**	**RTTA 3**	**RTTA 1**	**RTTA 2**	**RTTA 3**
Mini module	[NL, UEC]	[NL, UEC]	[UEC, DRF]	[BD, UEC]	[UEC, DRF]	[NL, DRF]	[*BD*, NL]	[NL, UEC]	[UEC, DRF]
Small module	[NL, UEC]	[NL, UEC]	[UEC, DRF]	[NL, UEC]	[UEC, DRF]	[NL, UEC]	[NL, UEC]	[NL, UEC]	[NL, DRF]
Standard module	[NL, UEC]	[UEC, DRF]	[UEC, DRF]	[UEC, DRF]	[UEC, DRF]	[NL, UEC]	[UEC, DRF]	[NL, UEC]	[NL, DRF]
Large module	[NL, UEC]	[UEC, DRF]	[UEC, DRF]	[UEC, DRF]	[UEC, DRF]	[NL, UEC]	[UEC, DRF]	[UEC, DRF]	[UEC, DRF]

Table A.17
2-tuple values for solar energy investments.

	Governmental policies		Location		Alternative energy sources	
	Opt.	Pess.	Opt.	Pess.	Opt.	Pess.
Mini module	(UEC,.33)	(NL,0)	(DRF,−.33)	(UEC,−.33)	(UEC,0)	(NL,0)
Small module	(UEC,0)	(NL,0)	(UEC,.33)	(NL,.33)	(UEC,.33)	(NL,.33)
Standard module	(UEC,.33)	(NL,.33)	(DRF,−.33)	(UEC,−.33)	(UEC,.33)	(UEC,−.33)
Large module	(DRF,0)	(UEC,−.33)	(DRF,0)	(UEC,−.33)	(UEC,.33)	(UEC,−.33)
	Cost		**Demand**		**Financial facilities**	
	Opt.	**Pess.**	**Opt.**	**Pess.**	**Opt.**	**Pess.**
Mini module	(UEC,.33)	(NL,.33)	(DRF,−.33)	(NL,0)	(UEC,0)	(NL,0)
Small module	(UEC,.33)	(NL,.33)	(UEC,.33)	(NL,.33)	(UEC,.33)	(NL,0)
Standard module	(DRF,−.33)	(UEC,−.33)	(DRF,−.33)	(UEC,−.33)	(DRF,−.33)	(NL,.33)
Large module	(DRF,−.33)	(UEC,−.33)	(DRF,−.33)	(UEC,−.33)	(DRF,0)	(UEC,0)

Table A.18
Interval-valued intuitionistic fuzzy sets for solar energy investments.

	Governmental policies	Location	Alternative energy sources	Cost	Demand	Financial facilities
Mini module	((.60,.67), (.20,.40))	((.60,.73), (.40,.53))	((.40,.60), (.20,.40))	((.60,.67), (.40,.47))	((.60,.73), (.20,.40))	((.40,.60), (.20,.40))
Small module	((.40,.60), (.20,.40))	((.60,.67), (.40,.47))	((.60,.67), (.40,.47))	((.60,.67), (.40,.47))	((.60,.67), (.40,.47))	((.60,.67), (.20,.40))
Standard module	((.60,.67), (.40,.47))	((.60,.73), (.40,.53))	((.60,.67), (.40,.53))	((.60,.73), (.40,.53))	((.60,.73), (.40,.53))	((.60,.73), (.40,.47))
Large module	((.60,.80), (.40,.53))	((.60,.80), (.40,.53))	((.60,.67), (.40,.53))	((.60,.73), (.40,.53))	((.60,.73), (.40,.53))	((.60,.80), (.40,.60))

made for the improvements of solar energy investments. Additionally, the proposed model of this study can also be improved in the following evaluations. This situation gives an opportunity to make comparative analysis. In this context, q-rung orthopair fuzzy sets can also be taken into consideration.

The future directions of research can be analysis of the importance of investing in energy technologies for the success of solar energy projects. The energy technologies can make solar energy projects more efficient and cost-effective, leading to a brighter future for renewable energy.

CRediT authorship contribution statement

Hasan Dinçer: Writing – original draft, Conceptualization, Methodology, Software. **Serhat Yüksel:** Writing – original draft, Conceptualization, Methodology, Software. **Tamer Aksoy:** Writing – original draft, Conceptualization, Methodology, Software. **Ümit Hacıoğlu:** Writing – original draft, Conceptualization, Methodology, Software. **Alexey Mikhaylov:** Data curation, Visualization, Investigation, Writing – original draft. **Gabor Pinter:** Software, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix

Table A.19
Defuzzifed decision matrix for solar energy investments.

	Governmental policies	Location	Alternative energy sources	Cost	Demand	Financial facilities
Mini module	.933	1.133	.800	1.067	.967	.800
Small module	.800	1.067	1.067	1.067	1.067	.933
Standard module	1.067	1.133	1.100	1.133	1.133	1.100
Large module	1.167	1.167	1.100	1.133	1.133	1.200

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