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Sustainable Energy Solutions: Evaluation of Solar Panel Installation Using Fuzzy Multi-Criteria Decision-Making Methods

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ABSTRACT

This study evaluates solar panel installation decisions by applying a hybrid fuzzy multi-criteria decision-making (FMCDM) methodology, integrating the Fuzzy Logarithm Methodology of Additive Weights (F-LMAW) for criterion weighting and the Fuzzy Alternative Ranking Technique based on Adaptive Standardized Intervals (F-ARTASI) for ranking alternatives. The primary aim is to identify and prioritize critical criteria influencing solar panel installation and optimize the decision-making process to propose sustainable and strategic solutions. Eighteen comprehensive criteria-ranging from installation costs and energy efficiency to environmental impact and public acceptance-were analyzed across five potential locations in Turkey: Gürün, Kangal, Divrigi, Altınyayla, and Imranlı.

The findings highlight that the ranking of alternatives remains consistent under varying F-Bonferroni mean aggregation operator parameters ($\boldsymbol{p}$ and $\boldsymbol{q}$), demonstrating the robustness and reliability of the adopted approach. Sensitivity analysis confirmed that the established criteria play a decisive role in the ranking, with Gürün consistently ranked first across all scenarios. Validation of the F-ARTASI results against established FMCDM methods, including F-TOPSIS, F-CoCoSo, F-MARCOS, F-WASPAS, and F-RAWEC, showed high consistency, with Spearman Correlation Coefficients (SCC) averaging 0.90. This reinforces the methodological reliability of the proposed model and underscores its applicability in real-world energy management scenarios.

The study provides valuable insights for decision-makers in optimizing solar energy projects, emphasizing the importance of systematic and analytical frameworks. Moreover, the consistent alignment of rankings across multiple methods suggests a flexible and reliable decision-making approach that is adaptable to different contexts. While the findings offer robust guidance for solar panel installations, the study acknowledges limitations in data generalizability and calls for further exploration into evolving criteria, such as emerging technologies and climate-specific conditions. Future research should focus on integrating advanced FMCDM techniques and expanding the framework to broader sustainable energy initiatives.

1. Introduction

The growing demand for sustainable energy solutions globally has led to significant developments in renewable energy technologies. These developments have made energy systems more environmentally friendly, economical and efficient, and have contributed to reducing dependence on fossil fuels. Solar energy, one of the renewable energy sources, plays an important role in the global energy transition as it offers solutions to critical problems such as combating climate change, energy security, and economic sustainability [1]. Solar energy stands out as one of the

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cornerstones of the transition to clean energy systems with its low greenhouse gas emissions, environmentally friendly structure and cost-effectiveness. Solar panel installations provide high efficiency in energy production and scalability for a variety of applications, while also offering long-term benefits from an economic point of view [2-3].

However, it is of great importance to make the right decisions in order to fully exploit the potential of solar energy. Solar panel installation is a process that is shaped not only by economic analyses and technical requirements, but also by many different factors such as environmental impacts, social acceptance, and local conditions [4-5]. In order to increase the effectiveness of solar energy systems at local and regional levels, many criteria need to be considered. These multidimensional assessments require complex decision-making processes that also involve various perspectives of different stakeholders and experts [6]. Therefore, it is critical to use more analytical and systematic approaches in decision-making processes in order to achieve optimal results [7].

In this regard, this study uses FMCDM methods to address the complexities in the evaluation of solar panel installations. In particular, the study uses the F-LMAW method to determine the criterion weights and the F-ARTASI method to rank the alternatives. These methods allow decision-makers to better manage uncertainties and subjective perceptions, while also increasing the consistency and reliability of decision processes.

The main objectives of this research are as follows:

- ✓ Determining the basic criteria affecting solar panel installation decisions and prioritizing these criteria.
- ✓ Determination of criterion weights with the F-LMAW method and ranking of solar panel installation alternatives with the F-ARTASI method.
- ✓ Providing decision support to policymakers, stakeholders and industry practitioners by providing strategic insights to optimize solar panel installations.

The study provides a scientific and analytical framework for the evaluation of solar energy projects, allowing decision-makers to make healthier and more efficient choices about sustainable energy solutions. As a result, this research aims to improve decision-making processes in renewable energy investments, guide them with systematic and reliable decision-making methods, and ensure more efficient implementation of clean energy projects such as solar energy. This systematic approach to solar panel installations will make significant contributions to the field of sustainable energy and allow for the development of more effective energy management strategies in the long term.

Although the existing literature discusses the MCDM methods used in solar panel installation and their effectiveness, most studies are limited to a single method in the process of weighting certain criteria or ranking alternatives. In addition, sensitivity analysis of the methods used or validation of the results with other methods are not sufficiently included.

In this context, in particular:

- ✓ Use of the Fuzzy LMAW method in criteria weighting and subjecting the weights obtained with this method to a detailed sensitivity analysis,
- ✓ Ranking the alternatives with the Fuzzy ARTASI method and verifying this ranking in comparison with other MCDM methods in the literature,

- ✓ Performing a detailed sensitivity analysis on the Bonferroni mean aggregation operator parameters

represents an area that has not been addressed in existing studies. The study aims to fill this gap in the literature not only to optimize solar panel installation decisions, but also to increase the reliability of these decisions and to provide strategic insights into energy management processes.

2. Literature Review

In this section, some studies in the literature on site selection of solar energy projects, LMAW method and ARTASI method will be examined. The successful implementation of solar energy projects depends on choosing the right location. For this reason, studies to determine the most appropriate areas by using various decision-making methods gain importance. MCDM methods such as LMAW and ARTASI contribute to the ranking of alternatives by analyzing the effect of different criteria. In this section, some of the studies on each method will be discussed in detail and how these methods can be integrated into site selection processes in solar energy projects will be discussed.

2.1 Studies on Site Selection in Solar Energy Projects

Solar energy has gained an important place among sustainable energy sources and has become a prominent area in renewable energy investments, especially in recent years. The installation of solar power plants requires the right location selection in order to increase energy production efficiency, ensure environmental sustainability and maximize economic returns. In this context, MCDM methods emerge as effective tools used in solar power plant site selection decisions. The studies in the literature have contributed to this process with different methods and criteria and presented various application examples.

In site selection analysis, studies carried out with multi-criteria decision-making models have an important place. Hosouli and Hassani [8] used the Fuzzy Analytical Hierarchy Process (FAHP) method in determining the most suitable locations for solar power plant installation in the UK. In this study, meteorological factors such as temperature, annual sunshine duration and humidity, as well as spatial factors such as roads and proximity to the power grid, were also taken into account. In this study, in which a MATLAB-based program was also used, a hierarchy was created between the criteria to support site selection decisions and Torquay was determined as the most suitable place. Wang *et al.,* [9] proposed an integrated multi-criteria decision-making model in determining the optimal location for solar power plant installation in Vietnam. In the study, 46 locations were evaluated with DEA, criterion weights were calculated with FAHP and ranking was made with TOPSIS. The results showed that Binh Thuan is the most suitable region. The research contributes to the literature by offering a flexible approach that can be applied in an environment of uncertainty in renewable energy projects. Shehab *et al.,* [6] identified suitable areas for solar power plants in the Erbil region of Iraq and compared MCDM methods such as the Analytical Hierarchy Process (AHP), TOPSIS, and SAW. The study created conformity maps by effectively using GIS and highlighted the differences between these methods. It has been determined that the SAW method gives more consistent results than other methods. Deveci *et al.,* [10] proposed the Fuzzy Logarithmic Weight Estimation method to determine the criterion weights for solar power plant site selection. Bouraima *et al.,* [4] developed an integrated decision support system for Photovoltaic (PV) solar energy systems and combined SWOT analysis and MCDM methods. In this study, especially in cases of uncertain and incomplete information, the IVIF-CoCoSo method was used and the criteria were prioritized. The study made recommendations on reducing environmental impacts and improving economic strategies. In another study on the Baltic region, Saraji *et al.,* [11] developed a two-stage model focused on efficiency and sustainability. In the first stage, regions with high potential were determined by Data Envelopment Analysis (DEA), and in the second stage, these regions were ranked by CRITIC-TOPSIS method. The results showed that the energy potentials of the identified regions were compatible with the Global Solar Atlas.

These studies in the literature emphasize the importance of MCDM methods used in site selection decisions in solar energy projects and reveal how the evaluation of different criteria together contributes to the decision processes. These researches, which are carried out in different countries and methods, provide valuable references for the planning processes of solar energy projects.

2.2 Studies on the LMAW Method

In recent years, MCDM methods have been among the important tools for solving complex decision problems. In this context, LMAW has come to the fore as an effective method for determining criterion weights, especially in cases involving uncertainty and turbidity. The applications of the LMAW method in different disciplines emphasize the flexibility of the methodology and its effectiveness in decision-making processes. Some studies based on the LMAW method in the literature are presented below:

Nasution *et al.,* [12] assessed the level of readiness of governments for AI using the fuzzy LMAW method integrated with the Schweizer-Sklar-weighted framework. The study used geometric and non-arithmetic functions instead of traditional arithmetic averages to more accurately analyze countries' rankings in the Oxford Insights AI Readiness Index. Countries were clustered according to observed criteria and in-depth insights on AI readiness were presented. This study demonstrates the accuracy and categorization capabilities of the LMAW method. Karakuş [13] used the Fuzzy LMAW method to evaluate the ecotourism potential for Sivas province. In the study, the Fuzzy LMAW method integrated with GIS was used to weight 24 different criteria. The calculations of the Ecotourism Potential Index (EPI) revealed different levels of ecotourism suitability in the study area. The results were supported by sensitivity analysis, which confirmed the validity and applicability of the proposed framework. Ecer *et al.,* [14] integrated fuzzy Z-numbers and LMAW method in the selection of sustainable cold supply chain suppliers for the Indian healthcare sector. In the research, the decision-making process was analyzed on the basis of economic, environmental and technical criteria and job creation, cost-effectiveness and the use of renewable resources were determined as the most important criteria. The combination of LMAW and TOPSIS methods has provided an effective approach to modeling ambiguous information. Puška *et al.,* [15] applied the fuzzy-rough LMAW method in the prioritization of devices to be used in the management of health waste in Bosnia and Herzegovina. In the study, the importance levels of the criteria were determined and air emissions and annual usage costs were identified as the most critical factors. The LMAW method combined with the fuzzy-rough CoCoSo method in the sequencing of the devices provided a reliable solution in terms of consistency and validity of the results. Haseli *et al.,* [16] integrated the LMAW method with the MARCOS method for the evaluation of land use projects supported by green finance. In this study, four different alternatives were evaluated based on economic, environmental, technical and social criteria. The findings revealed that the most appropriate project should be inclusive, economically and environmentally balanced, and the proposed method has made significant contributions to the literature. Puška *et al.,* [17] combined the LMAW method with the newly developed RAWEC (Ranking Alternatives with Weights of Criterion) method in the selection of agricultural distribution center locations in Bosnia and Herzegovina. The LMAW method was used as an effective tool in the calculation of criterion weights, and the consistency of the results obtained in the ranking of alternatives with the RAWEC method was confirmed by sensitivity analysis. This study shows that the LMAW method stands out for its simplicity and ease of implementation.

These studies based on the F-LMAW method emphasize the applicability of the methodology in different fields and its contributions to decision-making processes. The method's effectiveness in managing uncertainties and criterion weighting makes it a powerful tool for future MCDM problems.

2.3 Studies on the ARTASI Method

The ARTASI method is a method developed to ensure the ranking of alternatives in multi-criteria group decision-making problems. This method is notable for its capacity to process uncertainties and subjective assessments of decision-makers. The ARTASI method uses standardized ranges to manage mismatches of expert opinions, allowing flexibility in the ordering of alternatives. This methodology is especially preferred in complex and uncertain decision-making processes.

Today, the ARTASI method is applied in different sectors and integrated into various decision-making problems. The SF-LODECI-ARTASI model developed by Yalçın *et al.,* [18] shows the effectiveness of the ARTASI method in ranking the importance of the criteria and alternatives in the selection of commercial insurance. This model addresses uncertainties with soft clusters, while offering a more flexible approach to the ranking process. Similarly, Pamučar *et al.*, [19] used the ARTASI method in the selection of big data platforms, providing decision-makers with a practical decision support tool on criterion weights and alternative ranking. The PFS-CIMAS-ARTASI model developed by Kara *et al.,* [20] is used in the selection of digital platforms in the field of human resources management. In this study, the alternative ranking power of the ARTASI method was tested by calculating the importance of the criteria with Picture Fuzzy Sets (PFS). The study revealed that the PFS-CIMAS-ARTASI model is powerful and feasible, as well as validated by different sensitivity analyses.

The advantages of the ARTASI method are especially evident in decision-making processes where uncertainty is intense and expert opinions are incompatible. Unlike traditional ranking methods, ARKASI allows for more accurate and flexible rankings by using adaptive standard ranges between the scores given by experts. This is a significant benefit, especially in situations where there are a large number of criteria and alternatives. The ARTASI method allows decision-makers to manage uncertainties and make rankings between alternatives more precisely.

3. Methodology

Solar panel installation is a critical factor that has a direct impact on the efficiency and sustainability of energy systems. Therefore, identifying appropriate strategies is vital to not only maximize energy production but also to minimize environmental and economic risks. This study aims to effectively optimize the decision-making process of solar panel installations, to make a systematic ranking by evaluating the necessary criteria in this context. In the study, the criteria will be weighted and alternatives will be listed by using F-LMAW and F-ARTASI methods.

In this context, the F-LMAW method will be used to calculate the weights of the criteria, and the F-Bonferroni sum operator will be used to combine expert opinions. In the final stage, the F-ARTASI method will be applied to compare solar panel installation alternatives and determine the most suitable option. The methodological framework shown in Figure 1 is based on the integration of expert knowledge, prioritization of criteria and ranking of strategic alternatives.

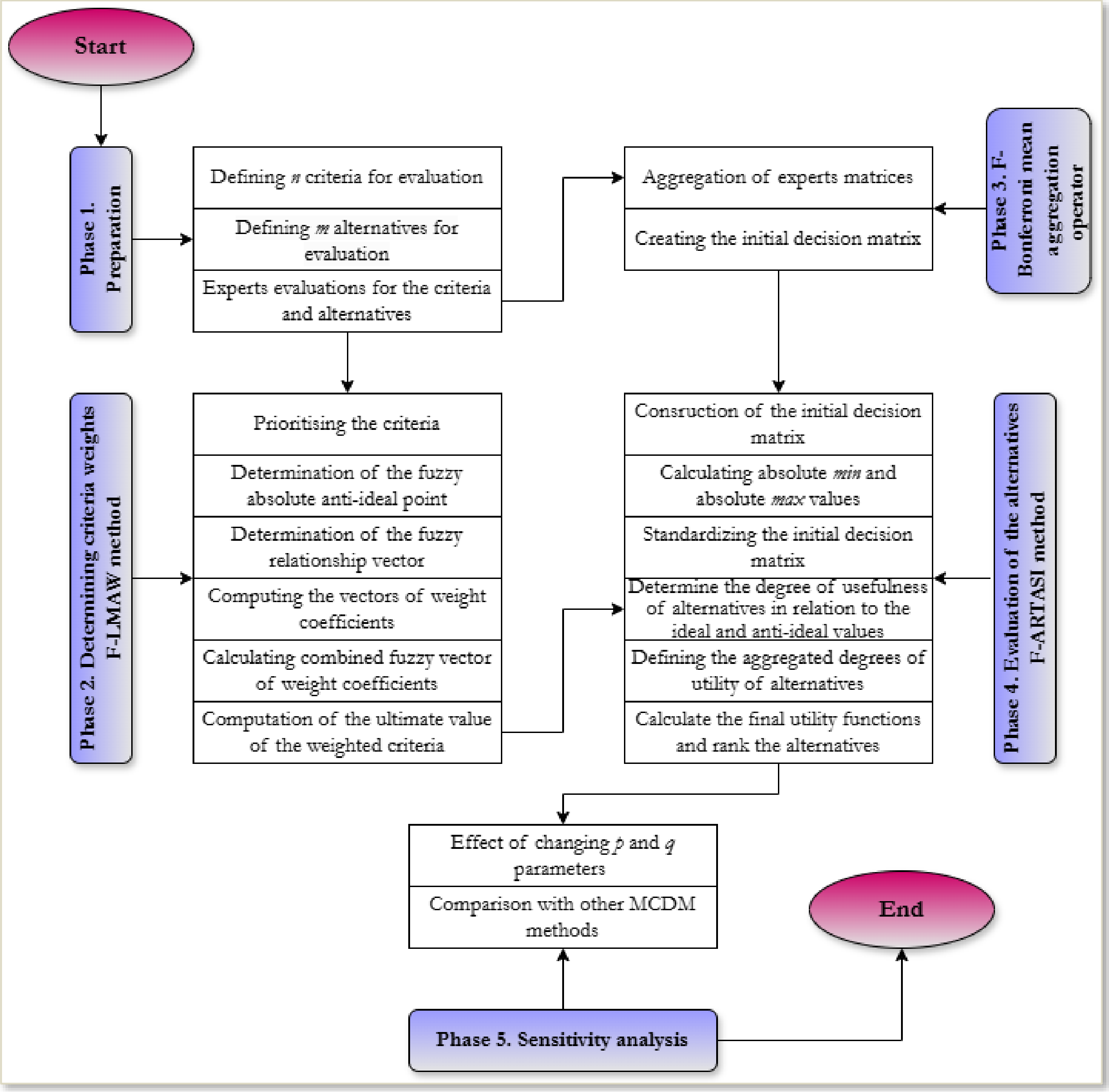

Fig. 1. F-Bonferroni mean aggregation-based F-LMAW and F-ARTASI framework

This study, the process steps of which are given in Figure 1, will present a comprehensive approach to the selection of appropriate strategies for the effective evaluation and implementation of solar panel installations. By calculating the weights of the determined criteria and combining the opinions of experts, the alternatives will be compared in detail and the most appropriate solution will be proposed. In this context, the outputs of the study will contribute to sustainable energy targets and provide strategic guidance to decision-makers.

3.1 Working Area

The Province of Sivas, situated in the Upper Kızılırmak Region of Central Anatolia, is the second-largest province in Turkey by land area, encompassing approximately 27386 km². Geographically, Sivas is located between the eastern longitudes of 36° and 39° and the northern latitudes of 38° and 41°, as illustrated in Figure 2.

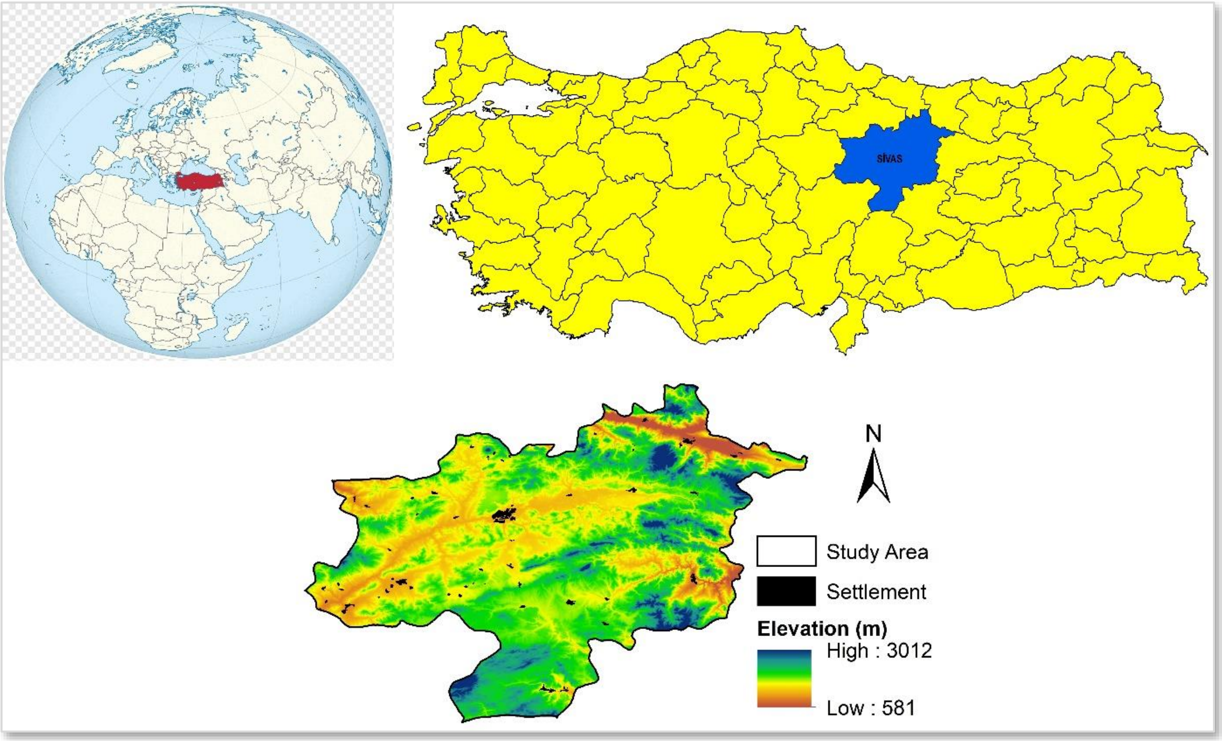

Fig. 2. Work area location

Since Turkey is located between the 36^0-42^0 northern parallels and the 26^0-45^0 eastern meridians, it is well located with 2737 hours of sunshine per year 7,5 hours of sunshine per day and an average annual solar energy amount of 1,527 kWh/m². Sivas in Figure 2 is the 45th most sunbathing province in Turkey with a total of 2653 hours of sunshine per year, while it ranks 37th in terms of radiation value [21].

3.2. Fuzzy Sets

Zadeh [22] proposed the fuzzy idea to address uncertainty in variables and parameters. Triangular fuzzy numbers (TFNs) have been used in various studies to turn qualitative assertions into quantitative ones. A TFN represents each figure with three numerals. The first, second, and third integers that define a fuzzy figure reflect the lowest, most, and highest potential values, respectively $\tilde{A}(l, m, u)$. Eq. (1) defines the triangle type membership function for fuzzy numbers.

$$\mu_A(x) = \begin{cases} 0, & x < l \\ \dfrac{x-l}{m-l}, & l \leq x \leq m \\ \dfrac{u-x}{u-m}, & m \leq x \leq u \\ 0, & x > u \end{cases} \tag{1}$$

TFNs can be transformed into crisp values by applying the center of gravity defuzzification technique represented by Eq. 2:

$$A = \frac{l + 4m + u}{6} \tag{2}$$

3.3 Fuzzy Bonferroni Aggregation Operator

Aggregation operators, which are mathematical functions, aggregate group members' individual preferences, evaluations, or judgments to form a common conclusion throughout the group decision-making process. The Bonferroni aggregation operator is based on fuzzy triangular numbers (TrFNs) operators and the operation of the TrFN. The Bonferroni Mean (TrFNBM) operator is provided by Eq. (3) Pamučar *et al.,* [23].

$\tilde{\varphi}_j = \left(\varphi_j^l, \varphi_j^m, \varphi_j^u\right), j = (1,2,\dots,n)$ be a collection of *TrFNs*, then the *TrFNBM* operator,

$$TrFNBM^{p,q,\rho}(\varphi_1,\varphi_2,\dots,\varphi_n) = \left(\frac{1}{n(n-1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\varphi_i^p\varphi_j^q\right)^{\frac{1}{p+q}} = \left(\left(\frac{1}{n(n-1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(\varphi_i^l\right)^p * \left(\varphi_j^l\right)^q\right)^{\frac{1}{p+q}}, \left(\frac{1}{n(n-1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}(\varphi_i^m)^p * \left(\varphi_j^m\right)^q\right)^{\frac{1}{p+q}}, \left(\frac{1}{n(n-1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}(\varphi_i^u)^p * \left(\varphi_j^u\right)^q\right)^{\frac{1}{p+q}}\right) \tag{3}$$

n is the number of experts, $p, q \geq 0$.

3.4. F-LMAW Method for Prioritization of Criteria

LMAW, which is employed to rank the decision alternatives and to find the weights of the evaluation criteria, was developed by Pamučar et al., [24]. The processing steps of the method are as follows Božanić et al., [25]:

Step 1: Prioritising the criteria

The identified experts prioritise the criteria using linguistic terms given in the fuzzy scale in Table 1.

Table 1.
Prioritization Scale

Fuzzy Linguistic Descriptive	Abbreviation	Fuzzy Number
Absolutely low	AL	(1,1,1)
Very low	VL	(1,1.5,2)
Low	L	(1.5,2,2.5)
Medium	M	(2,2.5,3)
Equal	E	(2.5,3,3.5)
Medium-high	MH	(3,3.5,4)
High	H	(3.5,4,4.5)
Very high	VH	(4,4.5,5)
Absolutely high	AH	(4.5,5,5)

Source: Božanić *et al.,* [25]

Using the fuzzy linguistic scale, significant values are assigned to the criteria of greater importance, and conversely. For each specialist, the priority vectors are obtained individually $\tilde{P}^e = \left(\tilde{\gamma}_{C_1}^e, \tilde{\gamma}_{C_2}^e, \dots, \tilde{\gamma}_{C_n}^e\right)$.

Step 2: Determination of the fuzzy absolute anti-ideal point ($\tilde{\gamma}_{AIP}$)

This fuzzy number, which is smaller than the smallest value in the whole collection of priority vectors, is established by experts. Those who brought the method to the literature used it as $\tilde{\gamma}_{AIP} =$ (0.5, 0.5, 0.5).

Step 3: Determination of the fuzzy relationship vector ($\tilde{R}^e$)

The connection between the components of the priority vector and the exact opposite ideal point is computed using Eq. (4).

$$\tilde{\eta}^e_{C_n} = \left(\frac{\tilde{\gamma}^e_{C_n}}{\tilde{\gamma}_{AIP}}\right) = \left(\frac{\gamma^{(l)e}_{C_n}}{\gamma^{(r)}_{A\dot{I}P}}, \frac{\gamma^{(m)e}_{C_n}}{\gamma^{(m)}_{A\dot{I}P}}, \frac{\gamma^{(r)e}_{C_n}}{\gamma^{(l)}_{A\dot{I}P}}\right) \tag{4}$$

Step 4: Computing the vectors (w^e_j) of weight coefficients

Eq. (5) is utilized to acquire the fuzzy score of the weight coefficients of the criteria of every expert.

$$\tilde{w}^e_j = \left(\frac{ln\left(\tilde{\eta}^e_{C_n}\right)}{ln\left(\prod_{j=1}^n \tilde{\eta}^e_{C_n}\right)}\right) = \left(\frac{ln\left(\eta^{(l)e}_{C_n}\right)}{ln\left(\prod_{j=1}^n \eta^{(r)e}_{C_n}\right)}, \frac{ln\left(\eta^{(m)e}_{C_n}\right)}{ln\left(\prod_{j=1}^n \eta^{(m)e}_{C_n}\right)}, \frac{ln\left(\eta^{(r)e}_{C_n}\right)}{ln\left(\prod_{j=1}^n \eta^{(l)e}_{C_n}\right)}\right) \tag{5}$$

The weight factors of all experts are acquired in the shape of $w^e_j = (\tilde{w}^e_1, \tilde{w}^e_2, \dots, \tilde{w}^e_n)^T$.

Step 5: Calculating combined fuzzy vectors of weight coefficients.

The combined fuzzy vectors of the weight coefficients are determined by utilizing the Bonferroni aggregator relying on Eq. (6) $w_j = (\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n)^T$.

$$\tilde{w}_j = \left(\frac{1}{k(k-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{k} \tilde{w}^{e(p)}_i \tilde{w}^{e(q)}_j\right)^{\frac{1}{p+q}} =$$

$$\left\{\left(\frac{1}{k(k-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{k} w_i^{(l_e)p} w_j^{(l_e)q}\right)^{\frac{1}{p+q}}, \left(\frac{1}{k(k-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{k} w_i^{(m_e)p} w_j^{(m_e)q}\right)^{\frac{1}{p+q}}, \left(\frac{1}{k(k-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{k} w_i^{(r_e)p} w_j^{(r_e)q}\right)^{\frac{1}{p+q}}\right\} \tag{6}$$

Step 6: Computation of the ultimate value of the weighted criteria.

The final values of the weight coefficients of the criteria are obtained through clarification based on $w_j = (w_1, w_2, \dots, w_n)^T$, as illustrated in Eq. (2).

3.5 F-ARTASI Method for Ranking Alternatives

Pamučar *et al.*, [19] presented the ARTASI technique for ranking alternatives (crisp version). In this study, the ARTASI technique is fuzzified using triangular fuzzy numbers.

Step 1. Construction of the initial decision matrix

The identified experts evaluate the alternatives using the linguistic terms given in the fuzzy scale in Table 1.

The initial decision matrix ($\tilde{\Delta}$) is obtained using Eq. (7).

$$\tilde{\Delta}=\left[\tilde{\wp}_{ij}\right]_{kxn}=\begin{bmatrix}\tilde{\wp}_{11} & \cdots & \tilde{\wp}_{1n}\\ \vdots & \ddots & \vdots\\ \tilde{\wp}_{k1} & \cdots & \tilde{\wp}_{kn}\end{bmatrix} \tag{7}$$

$\tilde{\wp}_{ij}=\left(\wp_{ij}^{l},\wp_{ij}^{m},\wp_{ij}^{u}\right)$ represents fuzzy value of criterion j. in alternative i.

Step 2. Calculating absolute minimum and absolute maximum values

The absolute maximum and absolute minimum values of the j^{th} criterion are obtained by Eqs. (8) and (9) respectively.

$$\tilde{\wp}_{j}^{max}=\left(\left(\max_{1\le i\le k}\wp_{ij}^{l}+\sqrt[k]{\max_{1\le i\le k}\wp_{ij}^{l}}\right),\left(\max_{1\le i\le k}\wp_{ij}^{m}+\sqrt[k]{\max_{1\le i\le k}\wp_{ij}^{m}}\right),\left(\max_{1\le i\le k}\wp_{ij}^{u}+\sqrt[k]{\max_{1\le i\le m}\wp_{ij}^{u}}\right)\right) \tag{8}$$

$$\tilde{\wp}_{j}^{min}=\left(\left(\min_{1\le i\le k}\wp_{ij}^{l}-\sqrt[k]{\min_{1\le i\le k}\wp_{ij}^{l}}\right),\left(\min_{1\le i\le k}\wp_{ij}^{m}-\sqrt[k]{\min_{1\le i\le k}\wp_{ij}^{m}}\right),\left(\min_{1\le i\le k}\wp_{ij}^{u}-\sqrt[k]{\min_{1\le i\le k}\wp_{ij}^{u}}\right)\right) \tag{9}$$

k denotes the number of alternatives, whereas $\tilde{\wp}_{j}^{max}$ and $\tilde{\wp}_{j}^{min}$ represent the absolute maximum and absolute minimum values, respectively.

Step 3. Standardizing the initial decision matrix

The architects of the method suggested standardizing the criteria values to the $\left[\Psi^{(l)},\Psi^{(u)}\right]$ ([1, 100]) criteria range for models with more than ten alternatives. For models with scales of 10 and less than 10, they said that smaller criterion interval thresholds could be adopted.

Step 3.1. In the first step, using Eq. (10), the initial decision matrix's elements are standardized as follows:

$$\tilde{\Delta}^{N}=\left[\tilde{\phi}_{ij}\right]_{kxn}$$

$$=\left(\begin{array}{c}\dfrac{\Psi^{(u)}-\Psi^{(l)}}{\left(\wp_{j}^{max}\right)^{l}-\left(\wp_{j}^{min}\right)^{l}}\wp_{j}^{l}+\dfrac{\left(\wp_{j}^{max}\right)^{l}.\Psi^{(l)}-\left(\wp_{j}^{min}\right)^{l}.\Psi^{(u)}}{\left(\wp_{j}^{max}\right)^{l}-\left(\wp_{j}^{min}\right)^{l}},\\ \dfrac{\Psi^{(u)}-\Psi^{(l)}}{\left(\wp_{j}^{max}\right)^{m}-\left(\wp_{j}^{min}\right)^{m}}\wp_{j}^{m}+\dfrac{\left(\wp_{j}^{max}\right)^{m}.\Psi^{(l)}-\left(\wp_{j}^{min}\right)^{m}.\Psi^{(u)}}{\left(\wp_{j}^{max}\right)^{m}-\left(\wp_{j}^{min}\right)^{m}},\\ \dfrac{\Psi^{(u)}-\Psi^{(l)}}{\left(\wp_{j}^{max}\right)^{u}-\left(\wp_{j}^{min}\right)^{u}}\wp_{j}^{u}+\dfrac{\left(\wp_{j}^{max}\right)^{u}.\Psi^{(l)}-\left(\wp_{j}^{min}\right)^{u}.\Psi^{(u)}}{\left(\wp_{j}^{max}\right)^{u}-\left(\wp_{j}^{min}\right)^{u}}\end{array}\right) \tag{10}$$

Step 3.2. If the criterion is of type ***min,*** the replacement of the values in the $\tilde{\Delta}^{N}= \left[\tilde{\phi}_{ij}\right]_{kxn}$ matrix by the reverse sorting algorithm is performed using Eq. (11).

$$\tilde{\xi}_{ij} = -\tilde{\phi}_{ij} + \max_{1\le i\le k}\tilde{\phi}_{ij} + \min_{1\le i\le k}\tilde{\phi}_{ij} = \begin{pmatrix} -\phi_j^l + \max\limits_{1\le i\le k}\phi_j^l + \min\limits_{1\le i\le k}\phi_j^l\,, \\ -\phi_j^m + \max\limits_{1\le i\le k}\phi_j^m + \min\limits_{1\le i\le k}\phi_j^m\,, \\ -\phi_j^u + \max\limits_{1\le i\le k}\phi_j^u + \min\limits_{1\le i\le k}\phi_j^u \end{pmatrix} \tag{11}$$

If the criteria is of the ***max*** type, $\tilde{\xi}_{ij} = \tilde{\phi}_{ij}$ is assumed.

Step 4. Determine the degree of usefulness of alternatives in relation to the ideal and anti-ideal values.

Step 4.1. Using Eq. (12), the degree of usefulness is determined in relation to the ideal value.

$$\tilde{\vartheta}_{ij}^{+} = \frac{\tilde{\xi}_{ij}}{\max\limits_{1\le i\le k}\left(\tilde{\xi}_{ij}\right)}\widetilde{w}_{ij}.\Psi^{(u)} = \begin{pmatrix} \dfrac{\xi_j^l}{\max\limits_{1\le i\le k}\xi_j^l}.w_j^l.\Psi^{(u)}, \\ \dfrac{\xi_j^m}{\max\limits_{1\le i\le k}\xi_j^m}.w_j^m.\Psi^{(u)}, \\ \dfrac{\xi_j^u}{\max\limits_{1\le i\le k}\xi_j^u}.w_j^u.\Psi^{(u)} \end{pmatrix} \tag{12}$$

Step 4.2. The degree of usefulness is defined relation to the ideal value using Eqs. (13) and (14). By applying Eq. (13), the values of the matrix are transformed.

$$\tilde{\vartheta}_{ij} = \frac{\min\limits_{1\le i\le k}(\tilde{\xi}_{ij})}{\tilde{\xi}_{ij}}\widetilde{w}_{ij}.\Psi^{(u)} = \begin{pmatrix} \dfrac{\min\limits_{1\le i\le k}\xi_j^l}{\xi_j^l}.w_j^l.\Psi^{(u)}, \\ \dfrac{\min\limits_{1\le i\le k}\xi_j^m}{\xi_j^m}.w_j^m.\Psi^{(u)}, \\ \dfrac{\min\limits_{1\le i\le k}\xi_j^u}{\xi_j^u}.w_j^u.\Psi^{(u)} \end{pmatrix} \tag{13}$$

While the use of Eq. (14) defines the degree of utility in relation to the anti-ideal value:

$$\tilde{\vartheta}_{ij}^{-} = -\tilde{\vartheta}_{ij} + \max_{1\le i\le k}\left(\tilde{\vartheta}_{ij}\right) + \min_{1\le i\le k}\left(\tilde{\vartheta}_{ij}\right) = \begin{pmatrix} -\vartheta_j^l + \max\limits_{1\le i\le k}\vartheta_j^l + \min\limits_{1\le i\le k}\vartheta_j^l, \\ -\vartheta_j^m + \max\limits_{1\le i\le k}\vartheta_j^m + \min\limits_{1\le i\le k}\vartheta_j^m, \\ -\vartheta_j^u + \max\limits_{1\le i\le k}\vartheta_j^u + \min\limits_{1\le i\le k}\vartheta_j^u \end{pmatrix} \tag{14}$$

Step 5. Defining the aggregated degrees of utility of alternatives.

Step 5.1. The total utility of the alternatives relative to the ideal value is calculated by Eq. (15).

$$\tilde{\Im}_j^+ = \sum_{j=1}^{n} \left(\tilde{\vartheta}_j^+\right) = \left(\sum_{j=1}^{n} \left(\vartheta_j^+\right)^l, \sum_{j=1}^{n} \left(\vartheta_j^+\right)^m, \sum_{j=1}^{n} \left(\vartheta_j^+\right)^u \right) \tag{15}$$

Step 5.2. The total utility of the alternatives relative to the anti-ideal value is calculated by Eq. (16).

$$\tilde{\Im}_j^- = \sum_{j=1}^{n} \left(\tilde{\vartheta}_j^-\right) = \left(\sum_{j=1}^{n} \left(\vartheta_j^-\right)^l, \sum_{j=1}^{n} \left(\vartheta_j^-\right)^m, \sum_{j=1}^{n} \left(\vartheta_j^-\right)^u \right) \tag{16}$$

Step 6. Calculate the final utility functions and rank the alternatives.

The utility functions for the alternatives are computed using Eq. (17).

$$\tilde{\Omega}_i = \left(\tilde{\Im}_j^+ + \tilde{\Im}_j^-\right). \sqrt[\varphi]{\alpha . f\left(\tilde{\Im}_j^+\right)^{\varphi} + (1-\alpha). f\left(\tilde{\Im}_j^-\right)^{\varphi}} = \begin{pmatrix} ((\Im_i^+)^l + (\Im_i^-)^l). \sqrt[\varphi]{\alpha . f\left(\Im_i^{+l}\right)^{\varphi} + (1-\alpha). f\left(\Im_i^{-l}\right)^{\varphi}}, \\ ((\Im_i^+)^l + (\Im_i^-)^l). \sqrt[\varphi]{\alpha . f\left(\Im_i^{+l}\right)^{\varphi} + (1-\alpha). f\left(\Im_i^{-l}\right)^{\varphi}}, \\ ((\Im_i^+)^l + (\Im_i^-)^l). \sqrt[\varphi]{\alpha . f\left(\Im_i^{+l}\right)^{\varphi} + (1-\alpha). f\left(\Im_i^{-l}\right)^{\varphi}} \end{pmatrix} \tag{17}$$

$\varphi \in [1, \infty), \alpha \in [0,1]$.

$$f\left(\tilde{\Im}_j^+\right) = \frac{\tilde{\Im}_j^+}{\tilde{\Im}_j^+ + \tilde{\Im}_j^-} = \left(\frac{(\Im_i^+)^l}{(\Im_i^+)^l + (\Im_i^-)^l}, \frac{(\Im_i^+)^m}{(\Im_i^+)^m + (\Im_i^-)^m}, \frac{(\Im_i^+)^u}{(\Im_i^+)^u + (\Im_i^-)^u} \right)$$

$$f\left(\tilde{\Im}_j^-\right) = \frac{\tilde{\Im}_j^-}{\tilde{\Im}_j^+ + \tilde{\Im}_j^-} = \left(\frac{(\Im_i^-)^l}{(\Im_i^+)^l + (\Im_i^-)^l}, \frac{(\Im_i^-)^m}{(\Im_i^+)^m + (\Im_i^-)^m}, \frac{(\Im_i^-)^u}{(\Im_i^+)^u + (\Im_i^-)^u} \right)$$

The utility function of alternatives has two parameters and φ and α. For more information [26]. For the final ranking of the alternatives, the final utility functions are used, where the alternative is desired to have the highest value.

4. Result

People from various fields of expertise were brought together to form a decision-making group to determine the optimal site selection for solar panel installations. Table 2 shows the structure of the decision-making group, which includes representatives from each area of expertise.

Table 2.
Profiles of Experts

Experts	Role	Responsibilities
Energy Engineer (E1)	Technical evaluation of solar energy systems	- Analyzing the efficiency and performance of solar panels and associated equipment

		- Assessing technical feasibility and system integration
Environmental Engineer/Scientist (E2)	Assessment of environmental impacts and sustainability criteria	- Examining the environmental impacts of solar panel installations - Analyzing effects on biodiversity, land use, and soil quality
Geographic Information Systems (GIS) Specialist (E3)	Spatial assessment and geographical data analysis	- Evaluating geographical criteria such as solar radiation, terrain suitability, and land cover - Creating suitability and compliance maps
Economist (E4)	Economic analysis and financial assessment	- Calculating installation, operational, and maintenance costs - Conducting return-on-investment analysis and evaluating economic sustainability

The expert team in Table 2 plays a critical role in determining the right strategies for solar panel installations.

4.1. Definition and Explanation of Criteria

The criteria used for site selection of solar panel installations are explained in detail by the expert team and presented in Table 3. These criteria have been carefully determined in order to best assess the efficiency, environmental impact and economic sustainability of the installation sites. Each criterion has a significant impact on the effectiveness and long-term success of solar energy systems.

Table 3.
Criteria for Selecting Locations for Solar Panel Installation

Criteria	Description
Installation Cost (C1)	Refers to the initial cost of solar panel installation. Lower costs make projects more accessible to a wider audience.
Energy Efficiency (C2)	Measures the energy production efficiency of solar panels, determining the amount of energy generated post-installation. Efficient systems produce more energy with less input.
Environmental Impact (C3)	Examines the environmental effects of solar energy systems, particularly concerning carbon emissions and resource use.
Installation Time (C4)	The duration required for installing solar panels is critical for project planning. Short installation times enable faster project implementation.
Energy Production Capacity (C5)	Assesses the potential energy production capacity of the panels. Higher capacity results in increased energy production and efficiency.
Payback Period (C6)	The time required for the investment to become profitable after installation. Short payback periods enhance financial sustainability.
Maintenance Costs (C7)	Regular maintenance costs for solar panel systems influence total operational expenses. Lower maintenance costs improve economic efficiency.
Panel Lifespan (C8)	The service life of panels affects long-term efficiency and investment longevity. Durable panels offer long-term profitability.
Suitability for Climate Conditions (C9)	Adaptability of panels to the climatic conditions of the installation region, impacting their efficiency. Performance varies across different climates.
Renewability Rate (C10)	Indicates the renewable energy utilization rate of the systems. Higher renewability rates promote environmental sustainability.
Change in Efficiency Over Time (C11)	Variations in panel efficiency over time serve as a long-term performance indicator. High efficiency ensures higher energy output.
Installation Area and Site Selection (C12)	The suitability of the installation area directly influences efficiency and energy production capacity. Proper site selection leads to more efficient systems.

Impact on Public Health (C13)	Evaluates the effects of solar energy projects on the health of the surrounding community. Panels may offer environmental and health benefits.
Energy Storage Capacity (C14)	The capacity to store generated energy. High storage capacity facilitates the management of energy production fluctuations.
Innovative Technologies and Methods (C15)	Advanced technologies and methods used in solar panel production can enhance system efficiency, enabling greater energy production.
Panel Production Process (C16)	The production process of panels impacts environmental and cost factors. Sustainable production methods reduce environmental impact.
Return on Investment (C17)	Determines how quickly the investment is recovered. Short recovery times are attractive to investors.
Social Acceptance and Public Support (C18)	Social acceptance of solar energy projects affects their success. Community support facilitates project implementation.

The criteria in Table 3 cover a wide range of factors that are important for solar panel installations. The criteria were evaluated in terms of economic, environmental, social and technical aspects. Each criterion represents important parameters that will affect the success and sustainability of solar panel systems. For example, while installation cost and maintenance costs are critical for economic sustainability, factors such as environmental impact and climate suitability have an impact on environmental impacts and efficiency. Criteria such as change in efficiency level and energy production capacity determine the long-term performance of the system, while factors such as its impact on public health and social acceptance affect the social success of the project.

4.2. Recommended Locations for The Installation of Solar Panels

Information for solar radiation in Sivas province is given in Figure 3.

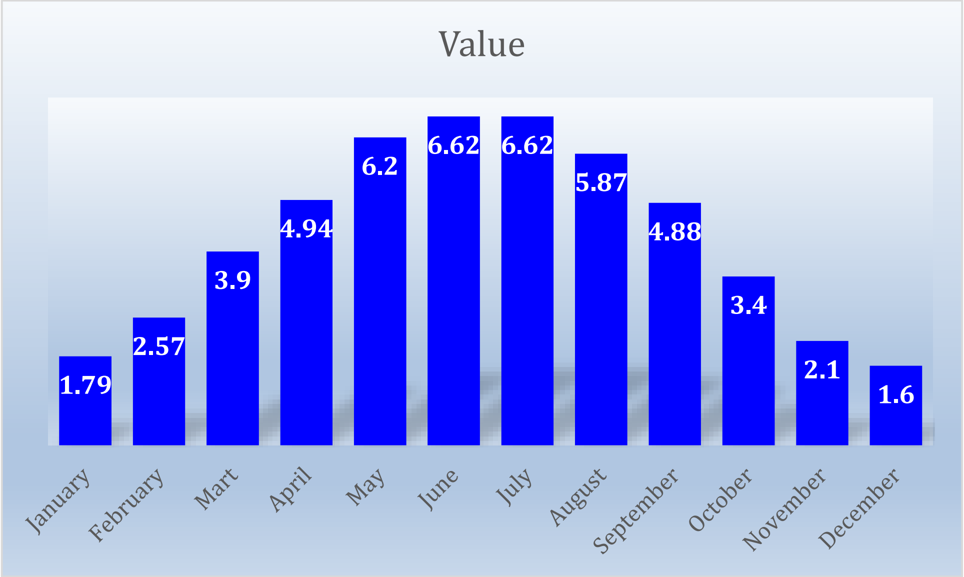

Fig. 3. Sivas Global Radiation Values (kWh/m²/day) [26]

The data in Figure 3 refer to the change in solar energy potential over the course of the year. In January and December, radiation values are at their lowest (January 1,79; Range 1,6). This reflects the low level of solar radiation during the winter months. June and July have the highest radiation values (6,62 kWh/m²/day). This indicates that the summer months are the most productive period for energy production. In the spring and autumn months (March-September), a gradual increase and decrease in radiation values is observed.

Information about the sunshine duration of Sivas is given in Figure 4.

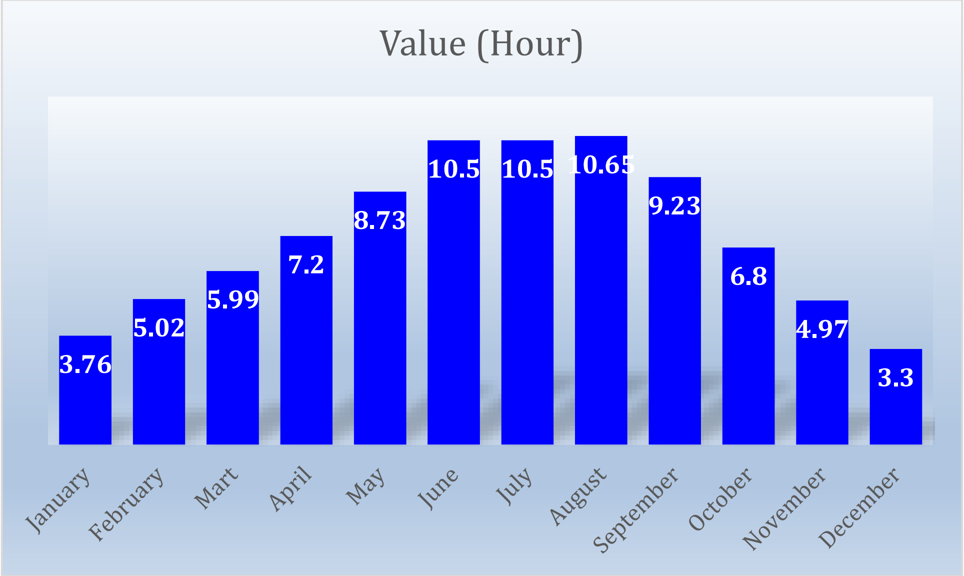

Fig. 4. Sivas Sunbathing Times (Hours) [26]

The data in Figure 4 is important for understanding the potential for solar power generation throughout the year. In January and December, the duration of sunshine is very low (January 3,76 hours; Range 3,3 hours). This refers to limited energy production during the winter months. June, July and August have the longest periods of sunshine (June and July 10,5 hours; August 10,65 hours). These months are the peak points in terms of energy production. In spring and autumn (March-September), the duration of sunshine gradually increases and decreases.

The solar energy potential of the districts of Sivas province is given in Figure 5.

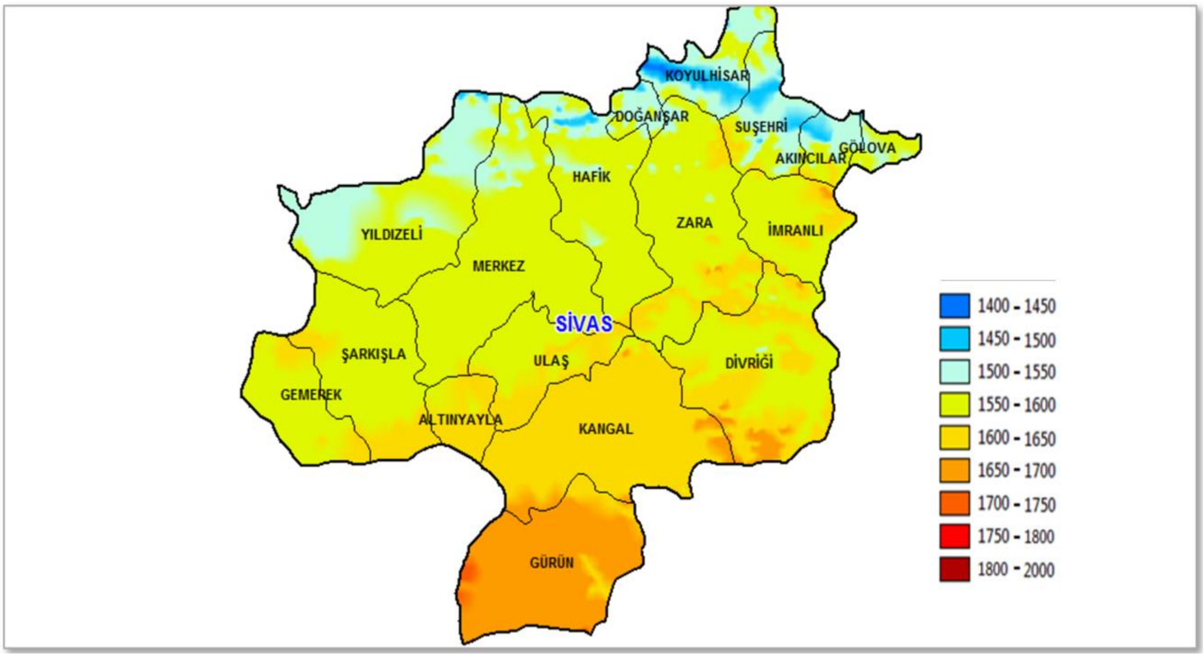

Fig. 5. Solar Energy Potential of Sivas Districts [26].

The map of Sivas province in Figure 5 shows that the southern and central districts have a high solar radiation potential. These regions are more efficient areas for energy production and are ideal locations for solar panel installations. In the winter months, considering the low solar radiation and short sunshine periods, sustainable energy production can be achieved throughout the year with energy storage systems. In the light of these data, experts have selected the most suitable places for solar panel installation in Sivas province and presented the characteristics of these places in Table 4.

Table 4.
Recommended Locations for Solar Panel Installation

Location	Features
Imranlı (A1)	High solar radiation, proximity to infrastructure, and low environmental impacts.
Altınyayla (A2)	Adequate solar radiation, high level of social acceptance, and low economic installation costs.
Divriği (A3)	Suitable altitude for solar panel efficiency, accessible infrastructure, and minimal ecological impacts.
Kangal (A4)	Moderate solar radiation, suitable land use, and favorable climatic conditions.
Gürün (A5)	High solar radiation levels, appropriate altitude, and low environmental impacts.

These recommendations in Table 4 have been prepared by experts evaluating the solar energy potential of Sivas, based on criteria such as solar radiation levels, access to infrastructure, and environmental sustainability.

4.3. Data Collection and Analysis

According to Table 1, the experts evaluated both the criteria and the available and proposed locations for solar panel installation. The evaluation of the criteria according to the expert opinions is given in Table 5, and the evaluation of the alternatives is given in Table 6.

Table 5.
Experts’ Evaluation of Criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
E1	VH	AH	MH	H	AH	VH	H	AH	VH	H	MH	E	MH	VH	H	MH	AH	MH
E2	MH	H	AH	E	H	MH	E	MH	AH	VH	H	VH	AH	H	VH	VH	MH	VH
E3	E	MH	VH	MH	H	E	E	MH	VH	H	VH	AH	H	MH	H	H	E	VH
E4	AH	VH	H	VH	AH	VH	AH	VH	H	MH	H	MH	MH	VH	VH	H	AH	H

Table 5 provides a summary of the scores given by experts to certain criteria. The criteria were evaluated and scored by each expert within the framework of their field of expertise. This scoring will help determine the weight of the criteria to be used in the final decision-making process.

Table 6.
Experts’ Evaluation of Alternatives

Recommended Places	Experts	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
A1	**E1**	MH	H	VH	E	VH	H	MH	AH	VH	H	MH	H	VH	H	AH	VH	H	AH
	E2	VH	AH	AH	MH	H	VH	AH	H	VH	MH	AH	MH	H	VH	H	MH	H	AH
	E3	H	MH	H	MH	VH	H	MH	VH	AH	MH	H	VH	H	MH	H	AH	H	MH

	E4	AH	H	MH	VH	AH	H	MH	AH	VH	H	VH	MH	H	VH	AH	H	E	MH
A2	**E1**	VH	MH	H	H	H	MH	VH	H	MH	AH	H	MH	H	E	MH	H	VH	E
	E2	H	MH	H	VH	MH	VH	H	VH	MH	AH	H	AH	AH	MH	VH	H	MH	E
	E3	VH	H	AH	H	MH	E	H	AH	E	AH	VH	MH	VH	AH	MH	MH	E	H
	E4	VH	MH	H	MH	H	MH	AH	H	MH	VH	MH	AH	VH	MH	H	VH	VH	H
A3	**E1**	H	VH	MH	MH	MH	VH	H	VH	H	MH	VH	AH	MH	AH	H	AH	MH	VH
	E2	MH	H	E	E	VH	H	MH	AH	H	VH	E	H	MH	AH	AH	VH	VH	H
	E3	MH	AH	VH	E	H	AH	VH	H	VH	H	MH	H	AH	E	VH	H	AH	VH
	E4	MH	VH	VH	E	MH	AH	H	E	H	AH	H	VH	MH	H	VH	MH	H	VH
A4	**E1**	E	E	H	VH	E	AH	E	MH	AH	VH	E	VH	E	MH	E	MH	AH	H
	E2	E	VH	MH	AH	E	MH	E	MH	E	H	VH	VH	E	H	E	AH	AH	VH
	E3	E	VH	MH	AH	AH	MH	E	MH	H	E	E	AH	E	H	AH	E	MH	AH
	E4	H	AH	AH	H	VH	E	VH	VH	AH	E	E	H	AH	AH	MH	E	AH	E
A5	**E1**	AH	MH	AH	H	AH	E	AH	H	E	E	AH	E	AH	VH	VH	H	E	MH
	E2	AH	MH	VH	H	VH	E	VH	H	AH	E	MH	E	VH	E	MH	H	E	MH
	E3	AH	MH	E	VH	E	VH	AH	H	MH	VH	AH	E	MH	VH	E	VH	VH	E
	E4	E	E	E	AH	E	VH	E	MH	E	MH	AH	E	E	E	E	AH	MH	AH

The assessment in Table 6 guides decision-makers to objectively understand the current state of alternatives in the context of sustainable energy solutions and to make choices in line with strategic priorities.

4.4 Determining the Weights with F-LMAW Method

The matrix obtained as a result of the experts' evaluations and presented in Table 5 were used as priority vectors for the criteria. Subsequently, the value of the absolute fuzzy anti-ideal spot was defined by experts as $\tilde{\gamma}_{AIP} = (0.5,\, 0.5,\, 0.5)$. For example, the relationship between the elements of the priority vector defined by E1 and the absolute anti-ideal point is calculated as follows.

$$\tilde{\eta}_{C1}^{E1} = \left(\frac{4}{0{,}5}, \frac{4{,}5}{0{,}5}, \frac{5}{0{,}5}\right) = (8{,}9{,}10), \ldots, \tilde{\eta}_{C18}^{E1} = \left(\frac{3}{0{,}5}, \frac{3{,}5}{0{,}5}, \frac{4}{0{,}5}\right) = (6{,}7{,}8).$$

For other specialists, calculations were made in a similar way. The determination of the vector of weight coefficients was made by applying Eq. (3). The calculation of the combined fuzzy vectors of the weight coefficients is done with the help of Eq. (4)- (6). Eq. (2) was applied for the final values of the weight coefficient obtained from the F-LMAW and the weights obtained are given in Figure 6.

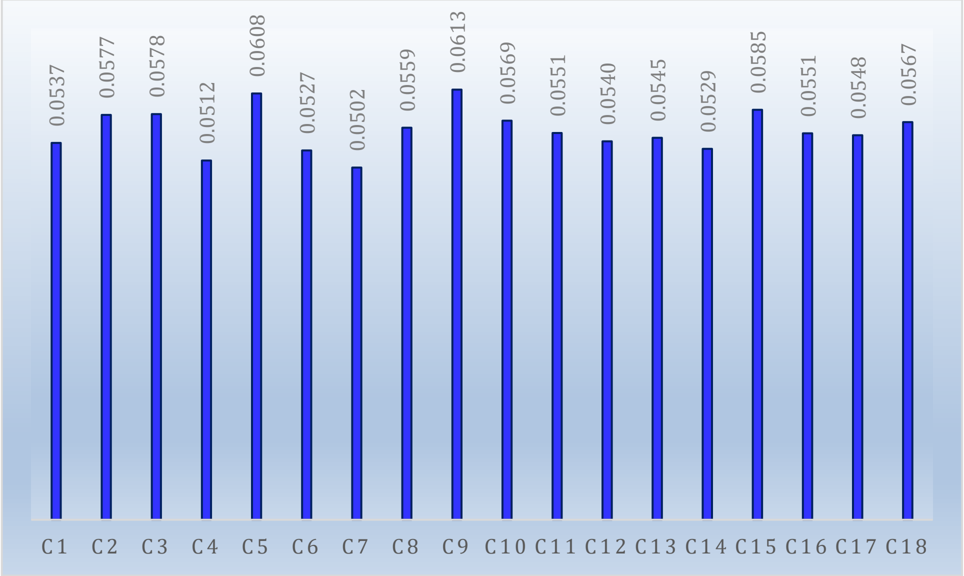

Fig. 6. Criteria Weights

The highest criterion with a weight value of 0,0613 in Figure 6 was “suitability for climatic conditions” (C9). This shows that climatic conditions are considered as the most important criterion in solar panel installation decisions. This is a critical criterion that particularly affects energy production capacity and sustainability. Power generation capacity (C5) ranked second with a weight value of 0,0608. This result indicates that capacity is of high importance in terms of technical performance and energy efficiency. Environmental impact (C3) is a very important criterion for environmental sustainability with a score of 0,0578. This reflects an approach in which environmentally conscious projects are preferred. Maintenance costs (C7) are one of the lowest importance criteria with a weight value of 0,0502. This suggests that decision-makers are focusing on other factors rather than long-term costs.

4.5. Fuzzy Bonferroni Aggregation Operator Application

The experts interpreted the performance of the alternatives according to Table 1. In order to bring these individual evaluations together, a combined fuzzy decision matrix was obtained using Eq. (3) and given in Appendix A.

4.6. F-ARTASI Method Application Results

The combined fuzzy decision matrix given in Appendix A is used as the initial decision matrix mentioned in the first step of the method. In the second step of the method, the absolute maximum and absolute minimum values of the jth criterion are calculated by Eqs. (8) and (9) respectively and given in Table 7.

Table 7.
Fuzzy absolute minimum and fuzzy absolute maximum values

			C1			C2			C3			C4			C5
$\tilde{\wp}_j^{max}$	5,2861	5,8214	6,2461	5,3140	5,8460	6,2461	5,0437	5,5778	5,9816	5,4453	5,9768	6,2461	5,3140	5,8460	6,2461
$\tilde{\wp}_j^{min}$	1,5154	1,9753	2,4397	1,6373	2,0974	2,5620	2,0630	2,5318	2,8937	1,4094	1,8668	2,3292	1,9812	2,4448	2,8937
			C6			**C7**			**C8**			**C9**			**C10**
$\tilde{\wp}_j^{max}$	5,4453	5,9768	6,2461	5,1783	5,7114	6,1133	5,4453	5,9768	6,2461	5,4506	5,9816	6,3797	5,7165	6,2461	5,4453

$\tilde{\wp}_j^{min}$	1,9575	2,4241	2,7861	1,6174	2,0803	2,5469	1,9753	2,4397	2,9075	1,6373	2,0974	2,5620	1,7351	2,1987	1,9575
			C11			**C12**			**C13**			**C14**			**C15**
$\tilde{\wp}_j^{max}$	6,3797	5,4345	5,9673	6,1087	5,3140	5,8460	6,2461	5,3140	5,8460	6,2461	5,0198	5,5569	5,9768	5,3140	5,8460
$\tilde{\wp}_j^{min}$	2,6659	1,6174	2,0803	2,5469	1,2989	1,7543	2,2153	1,7158	2,1820	2,5469	1,9575	2,4241	2,7861	1,7351	2,1987
			C16			**C17**			**C18**						
$\tilde{\wp}_j^{max}$	5,1783	5,7114	6,1133	5,4345	5,9673	6,1087	5,1840	5,7165							
$\tilde{\wp}_j^{min}$	1,8359	2,3024	2,6659	1,9753	2,4397	2,9075	1,7415	2,2042							

The fuzzy absolute maximum and fuzzy absolute minimum values of the C1 criteria in Table 7 are obtained as follows.

$$\tilde{\wp}_{C1}^{max} = \begin{pmatrix} \max\limits_{1\le i\le 5}\{3{,}7361\ \dots\ 3{,}9686\} + \sqrt[5]{\max\limits_{1\le i\le 5}\{3{,}7361\ \dots\ 3{,}9686\}}, \\ \max\limits_{1\le i\le 5}\{4{,}2377\ \dots\ 4{,}4721\} + \sqrt[5]{\max\limits_{1\le i\le 5}\{4{,}2377\ \dots\ 4{,}4721\}}, \\ \max\limits_{1\le i\le 5}\{4{,}6188\ \dots\ 4{,}6098\} + \sqrt[5]{\max\limits_{1\le i\le 5}\{4{,}6188\ \dots\ 4{,}6098\}}, \end{pmatrix} = (5{,}2861\ \ 5{,}8214\ \ 6{,}2461)$$

$$\tilde{\wp}_{C1}^{min} = \begin{pmatrix} \min\limits_{1\le i\le 5}\{3{,}7361\ \dots\ 3{,}9686\} - \sqrt[5]{\min\limits_{1\le i\le 5}\{3{,}7361\ \dots\ 3{,}9686\}}, \\ \min\limits_{1\le i\le 5}\{4{,}2377\ \dots\ 4{,}4721\} - \sqrt[5]{\min\limits_{1\le i\le 5}\{4{,}2377\ \dots\ 4{,}4721\}}, \\ \min\limits_{1\le i\le 5}\{4{,}6188\ \dots\ 4{,}6098\} - \sqrt[5]{\min\limits_{1\le i\le 5}\{4{,}6188\ \dots\ 4{,}6098\}}, \end{pmatrix} = (1{,}5154\ \ 1{,}9753\ \ 2{,}4397)$$

The third step of the procedure was to standardize the elements of the Appendix B matrix using Eqs. (10-11). The criteria values from Appendix E were translated into the criterion interval [1, 10], with the limit values $\Psi^{(l)}$=1 and $\Psi^{(u)}$=10. Limit values for criteria intervals $\Psi^{(l)}$=1 and $\Psi^{(u)}$=10) were determined based on expert judgments and the assumption that the interval [1,10] offers a suitable range for the distribution of utility functions of four options. Eq. (10) was used to conduct the transformation into the criteria interval [1, 10]. The next section describes the standardization technique for the element in table Appendix B positions A1-C1.

$$\tilde{\phi}_{A1,C1} = \begin{pmatrix} \dfrac{(10-1)}{(5{,}2861-1{,}5154)} * 3{,}7361 + \dfrac{(5{,}2861*1-1{,}5154*10)}{(5{,}2861-1{,}5154)}, \\ \dfrac{(10-1)}{(5{,}8214-1{,}9753)} * 4{,}2377 + \dfrac{(5{,}8214*1-1{,}9753*10)}{(5{,}8214-1{,}9753)}, \\ \dfrac{(10-1)}{(6{,}2461-2{,}4397)} * 4{,}6188 + \dfrac{(6{,}2461*1-2{,}4397*10)}{(6{,}2461-2{,}4397)} \end{pmatrix} = (6{,}3005\ \ 6{,}2941\ \ 6{,}1524)$$

All calculations were performed similarly and the standardized matrix is given in Appendix B.

Using Eq. (11), the values of Eq. (10) are standardized using the reverse sorting algorithm:

$$\tilde{\xi}_{A1,C1} = \begin{pmatrix} -6{,}3005 + \max\limits_{1\le i\le 5}\{6{,}3005 \dots 6{,}8555\} + \min\limits_{1\le i\le 5}\{6{,}3005 \dots 6{,}8555\}, \\ -6{,}2941 + \max\limits_{1\le i\le 5}\{6{,}2041 \dots 6{,}8427\} + \min\limits_{1\le i\le 5}\{6{,}2041 \dots 6{,}8427\}, \\ -6{,}1524 + \max\limits_{1\le i\le 5}\{6{,}1524 \dots\ 6{,}1311\} + \min\limits_{1\le i\le 5}\{6{,}1524 \dots\ 6{,}1311\} \end{pmatrix} = (4{,}4747\ \ 4{,}5088\ \ 4{,}6805)$$

In the fourth step of the method, Eqs. (12, 13) are used to determine the usefulness level of the alternatives using the ideal and anti-ideal values, Appendices C and D, respectively. The next section demonstrates how to define the degree of usefulness from Appendices C and D at positions A1-C1 (type min). Eq. (12) defines the degree of usefulness of alternative A1 for criteria C1 in relation to the ideal value as follows:

$$\tilde{\vartheta}^{+}_{A1,C1}=\begin{pmatrix}\dfrac{4,4747}{max\{4,4747\ \dots\ 3,9196\}}*0,0023*10,\\ \dfrac{4,5088}{max\{4,5088\ \dots\ 3,9603\}}*0,0030*10,\\ \dfrac{4,6805}{max\{4,6805\ \dots\ 4,7018\}}*0,0037*10\end{pmatrix}=(0,0153\ \ 0,0196\ \ 0,0259)$$

Defining the usefulness of alternative A1 for criteria C11 in respect to the anti-ideal value Eqs. (13, 14). Using Eq. (13), we find that:

$$\vartheta_{A1,C1}=\begin{pmatrix}\dfrac{min\{4,4747\ \dots\ 3,9196\}}{4,4747}*0,0023*10,\\ \dfrac{min\{4,5088\ \dots\ 3,9603\}}{4,5088}*0,0030*10,\\ \dfrac{min\{4,6805\ \dots\ 4,7018\}}{4,6805}*0,0037*10\end{pmatrix}=(0,0205\ \ 0,0261\ \ 0,0326)$$

Using Eq. (14), we determine the degree of usefulness of alternative A1 for criteria C1 in proportion to the anti-ideal value:

$$\tilde{\vartheta}^{-}_{A1,C1}=\begin{pmatrix}-0,0205+max\{0,0205\ \dots\ 0,0234\}+min\{0,0205\ \dots\ 0,0234\},\\ -0,0261+max\{0,0261\ \dots\ 0,0298\}+min\{0,0261\ \dots\ 0,0298\},\\ -0,0326+max\{0,0326\ \dots\ 0,0324\}+min\{0,0326\ \dots\ 0,0324\}\end{pmatrix}=(0,0163\ \ 0,0208\ \ 0,0274)$$

The remaining values from Appendices C and D are calculated in a similar way.

In the fifth step of the method, Eqs. (15) and (16) are used to define the total utility of the alternatives and are given in Table 8.

Table 8.
Aggregated utility degrees of alternatives

	$\tilde{\mathfrak{I}}_j^{+}$			$\tilde{\mathfrak{I}}_j^{-}$		
A1	0,3187	0,4191	0,5388	0,3304	0,4336	0,5545
A2	0,3452	0,4543	0,5756	0,3539	0,4648	0,5854
A3	0,3306	0,4326	0,5535	0,3417	0,4460	0,5668
A4	0,3676	0,4789	0,6199	0,3726	0,4851	0,6263
A5	0,3679	0,4821	0,6203	0,3730	0,4883	0,6280

The aggregate usefulness levels of the alternatives in Table 8 are obtained by summing the criteria values of Appendices C and D within each alternative.

In the sixth step of the method, the final utility functions of the alternatives were calculated using Eq. (17) and presented in Table 9. For the calculation of the terminal utility functions, φ=1 and α=0.5 values are accepted.

Table 9.
Fuzzy values of the utility functions of the alternatives

	$f(\tilde{\mathfrak{I}}_j^{+})$			$f(\tilde{\mathfrak{I}}_j^{-})$			$\tilde{\Omega}_i$		
A1	0,4910	0,4915	0,4928	0,5072	0,5085	0,5090	0,3240	0,4263	0,5477
A2	0,4938	0,4943	0,4958	0,5042	0,5057	0,5062	0,3488	0,4596	0,5816
A3	0,4918	0,4924	0,4941	0,5059	0,5076	0,5082	0,3353	0,4393	0,5615
A4	0,4966	0,4968	0,4975	0,5025	0,5032	0,5034	0,3698	0,4820	0,6236
A5	0,4966	0,4968	0,4969	0,5031	0,5032	0,5034	0,3704	0,4852	0,6243

The calculation of the final utility function of alternative A1 was performed as follows.

$$f(\tilde{\mathfrak{I}}_{A1}^{+})=\left(\frac{0{,}3187}{0{,}3187+0{,}3304},\frac{0{,}4191}{0{,}4191+0{,}4336},\frac{0{,}5388}{0{,}5388+0{,}5545}\right)=(0{,}4910\ \ 0{,}4915\ \ 0{,}4928)$$

$$f(\tilde{\mathfrak{I}}_{A1}^{-})=\left(\frac{0{,}5545}{0{,}5545+0{,}5388},\frac{0{,}4336}{0{,}4336+0{,}4191},\frac{0{,}3304}{0{,}3304+0{,}3187}\right)=(0{,}5072\ \ 0{,}5085\ \ 0{,}5090)$$

$$\tilde{\Omega}_{A1}=\begin{pmatrix}(0{,}3187+0{,}3304)\{0{,}5*0{,}4910^{1}+(1-0{,}5)*0{,}5072^{1}\}^{1/1}\\(0{,}4191+0{,}4336)\{0{,}5*0{,}4915^{1}+(1-0{,}5)*0{,}5085^{1}\}^{1/1}\\(0{,}5388+0{,}5545)\{0{,}5*0{,}4928^{1}+(1-0{,}5)*0{,}5090^{1}\}^{1/1}\end{pmatrix}=(0{,}3240\ \ 0{,}4263\ \ 0{,}5477)$$

Using Eq. (2), fuzzy values are converted into crips values and given in Table 10.

Table 10.
Ranking alternatives and utility functions

Alternatives	Ω_i	Rank
Imranlı	0,4295	5
Altınyayla	0,4615	3
Divrigi	0,4423	4
Kangal	0,4869	2
Gürün	0,4892	1

According to the ranking in Table 10, Gürün – 0,4892 has the highest utility function value. This indicates that the region has optimal conditions for solar panel installation. Kangal – 0,4869 ranked second in the ranking, showing strong performance, especially in environmental and economic criteria. Altınyayla – 0,4615 took third place and showed high performance, especially in technical criteria. Divrigi – 0,4423 was in fourth place and performed moderately. Imranlı – 0,4295 ranked fifth with the lowest utility function value.

5. Sensitivity Analysis and Validation of The Results

Sensitivity analysis and validation of the results obtained using the F-ARTASI method were performed. The sensitivity analysis takes into account the variation of the Bonferroni aggregation operator parameters (and). The comparison of the F-LMAW and F-ARTASI model with other models in the literature is presented as part of the validation results. For the comparison of the results of the considered MCDM models, a statistical correlation with the initial results was performed.

5.1. Sensitivity Analysis- Variation of p and q Parameters

The overall effect of the parameters p and q presented in the Bonferroni mean aggregation operator on the ranking of the presented alternatives in the proposed optimal intervention strategies selection management approach is analysed using a sensitivity analysis. Firstly, it can be observed that when the values of p and q are varied from 1 to 5, the ranking of all alternatives remains the same. Then, if we fix any of the parameters between 0 and 1, the difference in the ranking of the alternatives was also analysed. Again, the ranking of all alternatives remained the same. The results of the sensitivity analysis by changing the parameters are shown in Figure 7.

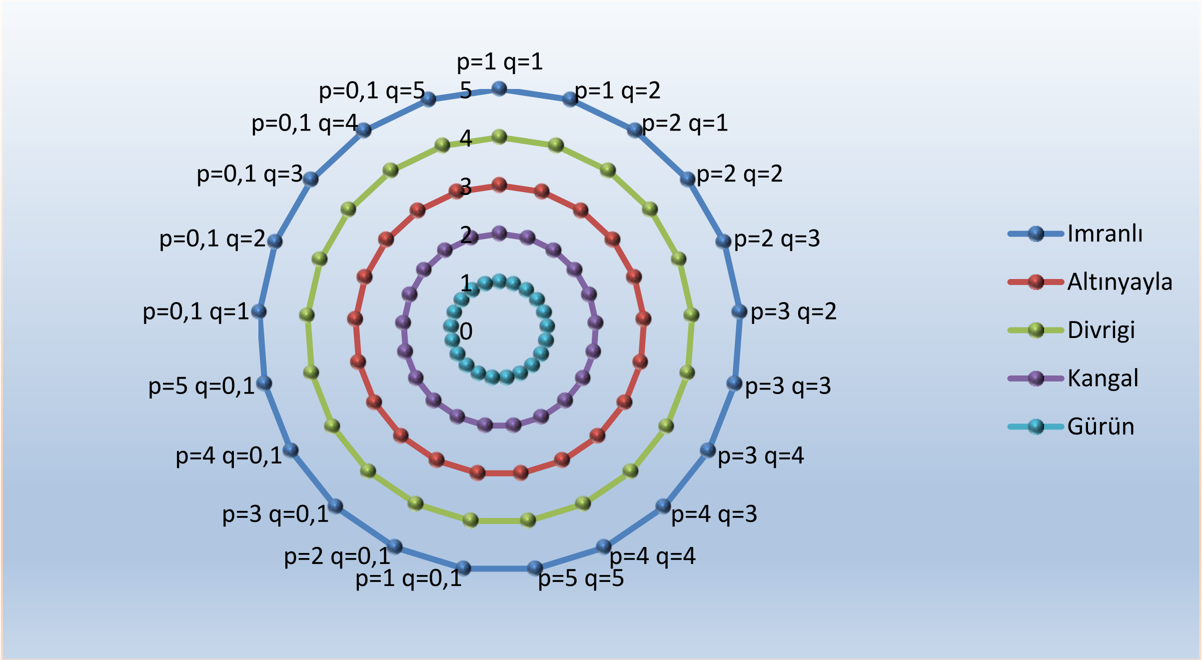

Fig. 7. Sensitivity analysis by varying the parameters p and q

The fact that the alternatives are in the same order in all the combinations in Figure 7 reveals a remarkable situation in terms of the consistency and reliability of the approach adopted for solar panel installation. In the context of determining important criteria for solar panel installation and selecting the optimum location, this situation is summarized in Table 11.

Table 11.
Parameter-Based Sensitivity Analysis Results

Evaluation	**Description**
Effect of Criteria	The consistent ranking of alternatives across all combinations clearly demonstrates the importance and influence of the criteria in the evaluation process. This highlights the decisive role of criteria in solar panel installation decisions.
Certainty in Decision-Making Process	The identical ranking of alternatives in all scenarios indicates that decision-makers (DMs) have clear perceptions and opinions about these alternatives. This clarity enables more precise and firm steps in solar panel installation decisions.
Strength of Systematic Approach	The consistent ranking in all combinations proves that the methods used are based on a systematic and analytical approach. This ensures that solar panel installation decision-making processes are grounded on solid foundations.
Strategic Planning and Implementation	The consistent ranking across combinations enhances the coherence of planning and implementation processes for solar panel installation strategies. This allows decision-makers to execute the identified strategies more effectively.

Likelihood of Achieving Goals	The identical ranking of alternatives in every combination reduces uncertainty in achieving solar panel installation objectives. This provides a strong basis for optimizing energy management processes and minimizing risks associated with installation.

Table 11 highlights the importance of consistency in the ordering of alternatives in solar panel installation.

5.2. Validation of Results- Comparison with Other MCDM Techniques

The results of the F-ARTASI method are compared with traditional multi-criteria models in the literature. For the comparison; CoCoSo method Yazdani *et al.,* [27], TOPSIS method Tzeng and Huang, [28], WASPAS method Zavadskas *et al.,* [29], MARCOS method Stević *et al.,* [30] and RAWEC method Puška *et al.,* [17] fuzzy versions were preferred. Figure 8 shows the results of the comparison of the mentioned FMCDM methods.

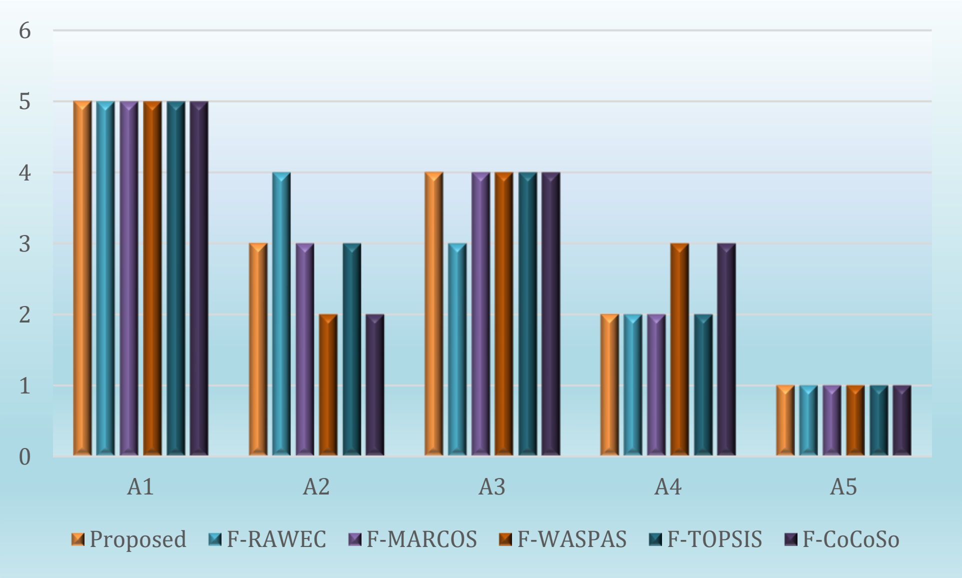

Fig. 8. Ranking Stability of Alternatives Using Various FMCDM methods

The sequences in Figure 8 provide an important finding to examine the consistency and reliability of different FMCDM methods in the decision process. The use of such methods in an area that requires multi-criteria decision-making, such as solar panel installation, reveals an analytical and systematic approach to the evaluation of alternatives.

- ✓ Overall Performance of Alternatives; A1 has consistently ranked 5th in all methods. This makes it clear that this alternative is an underperforming option. A5 has consistently ranked 1st in all methods. This shows that this alternative performs best in most of the criteria and is the strongest option.
- ✓ Consistency of Different Methods; It is seen that the results of F-RAWEC, F-MARCOS, F-WASPAS, F-TOPSIS and F-CoCoSo methods are largely parallel to each other. This shows that the methods produce consistent results in terms of the criteria used and provide a reliable evaluation. In particular, the fact that the A5 alternative is in the first place clearly states that

the decision processes in all methods meet at a common point and that this alternative should be prioritized.

- ✓ Impact and Consistency of Criteria; Figure 7 shows that the weights of the criteria and the computational mechanisms of the methods have a strong influence on the ranking. For example, A2 was found to be 2nd in some methods (F-MARCOS and F-WASPAS) and 3rd in others. A4 was generally ranked 2nd or 3rd.
- ✓ Implications for Decision Makers; A5 should be considered as a priority option because it ranks first in all methods. A2 and A4 are notable alternatives, ranking second and third in the ranking. A1 can be discarded due to its poor performance in all methods.

The fact that different methods produce the same or similar rankings shows that a correct approach is followed in the selection and weighting of criteria. This consistency offers reliable guidance in strategic decision-making processes such as solar panel installation. Prioritizing A5 can help drive more effective outcomes for sustainable energy solutions.

Since the overall ranking of the alternatives is the same in all methods, experts will reach similar results no matter which method they use. This shows that a flexible and reliable decision-making approach is adopted in the process of optimising occupational safety risks. The statistical correlation between the rankings obtained by the F-ARTASI procedure and the other procedures was determined by Spearman Correlation Coefficient (SCC). The findings regarding the comparison of the rankings by applying SCC are given in Table 12.

Table 12.
Rank correlations of the tested models

	F-CoCoSo	**F-MARCOS**	**F-WASPAS**	**F-TOPSIS**	**F-RAWEC**
F-ARTASI	0,90	1	0,90	1	0,70

From the results presented in Table 12, it can be concluded that there is a high correlation (average 0.90) between the ARTASI approach and the other five FMCDM procedures. As a result, it is possible to conclude that the ranking obtained from the proposed procedure is valid and reliable.

6. Discussion, Practical and Managerial Implications

The integration of F-ARTASI and F-LMAW methods for evaluating solar panel installation sites presents a robust framework for addressing the multi-dimensional and complex nature of decision-making in sustainable energy planning. This section discusses the theoretical, practical, and managerial implications of the study results, emphasizing their contribution to energy sustainability and strategic decision-making processes.

6.1. Theoretical Implications

The consistent rankings observed across all sensitivity analyses (varying parameters p and q in the Bonferroni mean operator) and validations against other FMCDM methods (e.g., F-CoCoSo, F-TOPSIS, F-MARCOS, F-WASPAS, and F-RAWEC) confirm the reliability of the F-ARTASI approach. This high correlation, as evidenced by Spearman Correlation Coefficients (average 0.90), reinforces the robustness of the proposed methodology.

- ✓ Impact of criteria The study highlights that criteria such as Installation Cost , energy efficiency and environmental impact play decisive roles in determining optimal solar panel locations, as their consistent weightings ensure reliable decision-making.
- ✓ Consistency and Systematic Approach The alignment of rankings with other FMCDM techniques substantiates the systematic and analytical nature of the proposed method, ensuring its adaptability across diverse energy planning scenarios.

6.2. Practical Implications

This study provides actionable insights for stakeholders in sustainable energy projects.

- ✓ Priorities in Energy Management: Gürün's consistent first rank across all methods and parameters underscores its superiority as the optimal location for solar panel installations. Decision-makers can focus on its development to achieve maximum energy production and sustainability outcomes.
- ✓ Performance Evaluation of Alternatives: The stable performance of other alternatives, such as Kangal (Rank 2) and Altınyayla (Rank 3), provides a hierarchy for resource allocation and infrastructure planning.
- ✓ Validity and Reliability: The validation process demonstrates that the use of F-ARTASI aligns with established methods, offering stakeholders confidence in adopting this approach for future projects.

6.3. Managerial Implications

The results have significant implications for decision-making, resource allocation, and strategic energy planning.

- ✓ Strategic Planning and Implementation: Consistent rankings across sensitivity analyses enable managers to develop and implement solar panel installation strategies with reduced uncertainty.
- ✓ Integration of criteria into Management Processes: The inclusion of criteria such as life of panels (C8), innovative technologies and methods (C15), and return on investment (C17) provides a holistic framework for assessing both technical and economic dimensions.
- ✓ Sustainability Strategies By prioritizing sites with high energy generation capacity (C5) and minimal environmental impact (C3), managers can align energy goals with environmental and social responsibilities.

The findings of this study underscore the strategic value of adopting advanced FMCDM methods like F-ARTASI for energy planning. By ensuring consistent, reliable, and practical decision-making, the proposed approach supports the development of sustainable energy infrastructure. Future research could focus on integrating more dynamic criteria or exploring the adaptability of this framework to other renewable energy domains.

7. Conclusions, Limitations, and Directions for The Future

This section includes summarizing the findings of the study, discussing the limitations of methods and applications, and presenting suggestions for future studies. The effectiveness of FMCDM methods used in the evaluation of solar panel installation sites and their contribution to decision processes are discussed both theoretically and practically.

7.1. Conclusions

This study demonstrated the effectiveness of MCDM approaches in the selection of solar panel installation sites in sustainable energy solutions. Determining the criterion weights with the F-LMAW method and ranking the alternatives with the F-ARTASI method provided both a systematic and consistent decision process.

- ✓ Determinism of Criteria: The significant impact of criteria such as installation cost (C1), energy efficiency (C2) and environmental impact (C3) in the evaluation process is emphasized. These criteria have played a critical role in ensuring the stability of the ranking results.
- ✓ Performance of Alternatives: Gürün has been determined as the most suitable installation location by ranking first in all methods. Kangal and Altınyayla were in second and third place respectively, while Imranli underperformed in fifth place.
- ✓ Reliability of Methods: The F-ARTASI method showed high correlation (mean Spearman Correlation Coefficient 0.90) in comparisons with other FMCDM methods (F-CoCoSo, F-TOPSIS, F-MARCOS, F-WASPAS and F-RAWEC). This result reveals the validity and reliability of the method used.

7.2. Limitations

While the findings of this study provide important insights, they have some limitations:

- ✓ Scope of Criteria and Alternatives: Although the criteria used in the study are comprehensive in the context of energy management, dynamics such as regional socio-economic factors or climate variability are not taken into account.
- ✓ Parameter Constancy The p and q parameters of the Bonferroni mean were analyzed, but the effect of different weighting approaches was not evaluated.
- ✓ Regional Scope: The study focused only on the province of Sivas. A broader geographic analysis may be useful for assessing the applicability of the method in other regions.
- ✓ Evaluation Based on Expert Opinions: The criteria and weights used were based on the opinions of specific experts. A wider stakeholder engagement could have offered a wider range of perspectives.

7.3. Future Directions

In line with the findings and limitations of this study, recommendations for future research and applications are listed below:

- ✓ Integration of Dynamic Criteria: The study can be enriched by integrating dynamic factors such as seasonal energy demand or regional climate variability into decision processes.
- ✓ Expansion of the Geographical Working Area: The applicability of the F-ARTASI method in energy infrastructure planning in different regions can be evaluated. This allows testing the generalizability of the method.
- ✓ Expanding the Criteria with a Multidisciplinary Approach: Addressing socio-economic, environmental and technical criteria in a broader framework can support sustainability goals more comprehensively.
- ✓ Combination of Different MCDM Methods: The integration of F-ARTASI, as well as other hybrid methods, can make decision processes more flexible and powerful.

- ✓ Integration of AI-Based Methods: The integration of AI-based algorithms into decision-making processes can provide more precise and predictive results with big data analysis.

This study provides a robust method for optimizing decision-making processes for sustainable energy solutions. This method of selecting solar panel installation sites contributes to energy management and environmental sustainability goals, while being a valuable reference source for future applications and research.

Appendix A.

Combined fuzzy decision matrix

			C1			C2			…			C18
A1	3,7361	4,2377	4,6188	3,6113	4,1130	4,4954	…	…	…	3,7249	4,2279	4,4907
A2	3,8730	4,3732	4,8734	3,1225	3,6228	4,1231	…	…	…	2,9861	3,4881	3,9896
A3	3,1225	3,6228	4,1231	3,9948	4,4954	4,8734	…	…	…	3,8730	4,3732	4,8734
A4	2,7386	3,2404	3,7417	3,7249	4,2279	4,6098	…	…	…	3,5998	4,1028	4,4861
A5	3,9686	4,4721	4,6098	2,8723	3,3727	3,8730	…	…	…	3,2210	3,7249	4,1130

Appendix B.

Standardized aggregated decision matrix

			C1			C2			…			C18
A1	6,3005	6,2941	6,1524	5,8321	5,8391	5,7232	…	…	…	6,1854	6,1856	5,5814
A2	6,6272	6,6112	6,7544	4,6355	4,6623	4,8138	…	…	…	4,2538	4,2898	4,3198
A3	4,8359	4,8553	4,9804	6,7708	6,7572	6,6467	…	…	…	6,5725	6,5580	6,5446
A4	3,9196	3,9603	4,0785	6,1102	6,1150	6,0026	…	…	…	5,8582	5,8651	5,5697
A5	6,8555	6,8427	6,1311	4,0230	4,0617	4,2027	…	…	…	4,8680	4,8967	4,6305
max	6,8555	6,8427	6,7544	6,7708	6,7572	6,6467	…	…	…	6,5725	6,5580	6,5446
min	3,9196	3,9603	4,0785	4,0230	4,0617	4,2027	…	…	…	4,2538	4,2898	4,3198

Appendix C.

Degrees of usefulness of alternatives in relation to the ideal value

			C1			C2			…			C18
A1	0,0153	0,0196	0,0259	0,0188	0,0236	0,0306	…	…	…	0,0176	0,0222	0,0321
A2	0,0142	0,0182	0,0226	0,0233	0,0291	0,0360	…	…	…	0,0249	0,0313	0,0397
A3	0,0203	0,0259	0,0324	0,0152	0,0192	0,0251	…	…	…	0,0161	0,0205	0,0262
A4	0,0234	0,0298	0,0374	0,0177	0,0223	0,0289	…	…	…	0,0188	0,0238	0,0322
A5	0,0134	0,0172	0,0260	0,0256	0,0320	0,0397	…	…	…	0,0226	0,0284	0,0379

Appendix D.

Degrees of usefulness of alternatives in relation to the anti-ideal value

			C1			C2			…			C18
A1	0,0163	0,0208	0,0274	0,0201	0,0251	0,0322	…	…	…	0,0182	0,0230	0,0335
A2	0,0147	0,0189	0,0226	0,0241	0,0301	0,0371	…	…	…	0,0249	0,0313	0,0397
A3	0,0213	0,0272	0,0339	0,0152	0,0192	0,0251	…	…	…	0,0161	0,0205	0,0262
A4	0,0234	0,0298	0,0374	0,0188	0,0236	0,0303	…	…	…	0,0197	0,0248	0,0335
A5	0,0134	0,0172	0,0275	0,0256	0,0320	0,0397	…	…	…	0,0233	0,0292	0,0384

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References

[1] Sassi, R., Souheil El, A. (2024). A GIS based MCDM modelling approach for evaluating large-scale solar PV installation in Tunisia. *Energy Reports*, 11, 580-596. https://doi.org/10.1016/j.egyr.2023.12.018.

[2] Haspolat, E., Cicek, D. D., Gokmener, S., Melek, A. B., Deveci, M., & Oguz, E. (2024). Site selection of floating photovoltaic systems on hydropower reservoirs using fuzzy sine trigonometric decision-making model: Turkey as a case study. *Renewable and Sustainable Energy Reviews*, 206, 114830. https://doi.org/10.1016/j.rser.2024.114830

[3] Melek, A. B., Gökmener, S., Haspolat, E., Çiçek, D. D., Deveci, M., Oğuz, E., & Khorasanchi, M. (2024). Fuzzy Einstein-based decision-making model for the evaluation of site selection criteria of floating photovoltaic system. *Ocean Engineering*, 301, 117521. https://doi.org/10.1016/j.oceaneng.2024.117521

[4] Bouraima, M. B., Ayyıldız, E., Badi, I., Özçelik, G., Yeni, F. B., & Pamučar, D. (2024). An integrated intelligent decision support framework for the development of photovoltaic solar power. *Engineering Applications of Artificial Intelligence*, 127, 107253. https://doi.org/10.1016/j.engappai.2023.107253

[5] Majumder, P., Bhowmik, P., Das, A., Senapati, T., Simic, V., & Pamučar, D. (2023). An intuitionistic fuzzy based hybrid decision-making approach to determine the priority value of indicators and its application to solar energy feasibility analysis*. Optik*, 295, 171492. https://doi.org/10.1016/j.ijleo.2023.171492

[6] Shehab, Z. N., Faisal, R. M., & Ahmed, S. W. (2024). Multi-Criteria Decision Making (MCDM) Approach for Identifying Optimal Solar Farm Locations: A Multi-Technique Comparative Analysis. *Renewable Energy*, 121787. https://doi.org/10.1016/j.renene.2024.121787

[7] Ünsal, Ö., Demir, G., Karakuş, C. B., & Pamučar, D. (2024). Application of Z-number based fuzzy MCDM in solar power plant location selection problem in Spatial planning. *Energy Reports*, 12, 4034-4054. https://doi.org/10.1016/j.egyr.2024.09.055

[8] Hosouli, S., & Hassani, R. A. (2024). Application of multi-criteria decision making (MCDM) model for solar plant location selection. *Results in Engineering*, 24, 103162. https://doi.org/10.1016/j.rineng.2024.103162

[9] Wang, C. -N., Nguyen, V. T., Thai, H. T. N., & Duong, D. H. (2018). Multi-Criteria Decision Making (MCDM) Approaches for Solar Power Plant Location Selection in Viet Nam. *Energies*, 11(6), 1504. https://doi.org/10.3390/en11061504

[10] Deveci, M., Cali, U., & Pamučar, D. (2021). Evaluation of criteria for site selection of solar photovoltaic (PV) projects using fuzzy logarithmic additive estimation of weight coefficients. *Energy Reports*, 7, 8805-8824. https://doi.org/10.1016/j.egyr.2021.10.104

[11] Saraji, M. K., Streimikiene, D., & Suresh, V. (2024). A novel two-stage multicriteria decision-making approach for selecting solar farm sites: A case study. *Journal of Cleaner Production*, 444, 141198. https://doi.org/10.1016/j.jclepro.2024.141198

[12] Nasution, M. K., Elveny, M., Pamučar, D., Popovic, M., & Gušavac, B. A. (2024). Uncovering the Hidden Insights of the Government AI Readiness Index: Application of Fuzzy LMAW and Schweizer-Sklar Weighted Framework. *Decision Making: Applications in Management and Engineering*, 7(2), 443-468. https://doi.org/10.31181/dmame7220241221

[13] Karakuş, C. B. (2024). Assessment of ecotourism potentiality based on GIS-based fuzzy logarithm methodology of additive weights (F-LMAW) method for sustainable natural resource management. *Environment, Development and Sustainability*, 26(10), 27001-27055. https://doi.org/10.1007/s10668-024-05283-0

[14] Ecer, F., Haseli, G., Krishankumar, R., & Hajiaghaei-Keshteli, M. (2024). Evaluation of sustainable cold chain suppliers using a combined multi-criteria group decision-making framework under fuzzy ZE-numbers. *Expert Systems with Applications*, 245, 123063. https://doi.org/10.1016/j.eswa.2023.123063

[15] Puška, A., Štilić, A., Pamučar, D., Simic, V., & Petrović, N. (2024). Optimal selection of healthcare waste treatment devices using fuzzy-rough approach. *Environmental Science and Pollution Research*, 1-20. https://doi.org/10.1007/s11356-024-32630-5

[16] Haseli, G., Deveci, M., Isik, M., Gokasar, I., Pamučar, D., & Hajiaghaei-Keshteli, M. (2024). Providing climate change resilient land-use transport projects with green finance using Z extended numbers based decision-making model. *Expert Systems with Applications*, 243, 122858. https://doi.org/10.1016/j.eswa.2023.122858

[17] Puška, A., Štilić, A., Pamučar, D., Božanić, D., & Nedeljković, M. (2024). Introducing a Novel multi-criteria Ranking of Alternatives with Weights of Criterion (RAWEC) model. *MethodsX*, 102628. https://doi.org/10.1016/j.mex.2024.102628

[18] Yalçın, G. C., Kara, K., & Senapati, T. (2024). A hybrid spherical fuzzy logarithmic decomposition of criteria importance and alternative ranking technique based on Adaptive Standardized Intervals model with application. *Decision Analytics Journal*, 11, 100441. https://doi.org/10.1016/j.dajour.2024.100441

[19] Pamučar, D., Simic, V., Görçün, Ö. F., & Küçükönder, H. (2024). Selection of the best Big Data platform using COBRAC-ARTASI methodology with adaptive standardized intervals. *Expert Systems with Applications*, 239, 122312. https://doi.org/10.1016/j.eswa.2023.122312

[20] Kara, K., Yalçın, G. C., Kaygısız, E. G., Simic, V., Örnek, A. Ş., & Pamučar, D. (2024). A Picture Fuzzy CIMAS-ARTASI Model for Website Performance Analysis in Human Resource Management. *Applied Soft Computing*, 111826. https://doi.org/10.1016/j.asoc.2024.111826

[21] https://www.gnssolar.com/icerik/860/turkiye-gunes-haritasi (Access: 01.12.2024).

[22] Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*. 8(3), 338-353. https://doi.org/10.1016/S0019-9958(65)90241-X

[23] Pamučar, D., Deveci, M., Canıtez F., Bozanic. D. (2020). A fuzzy Full Consistency Method-Dombi-Bonferroni model for prioritizing transportation demand management measures. *Applied Soft Computing*, 87, 105952. https://doi.org/10.1016/j.asoc.2019.105952

[24] Pamučar, D., Žižović, M., Biswas, S., & Božanić, D. (2021). A new logarithm methodology of additive weights (LMAW) for multi-criteria decision-making: Application in logistics. *Facta Universitatis, Series: Mechanical Engineering,* 19(3), 361-380. https://doi.org/10.22190/FUME210214031P

[25] Božanić, D., Pamučar, D., Milić, A., Marinković, D., & Komazec, N. (2022). Modification of the logarithm methodology of additive weights (LMAW) by a triangular fuzzy number and its application in multi-criteria decision making. *Axioms*, 11(3), 89. https://doi.org/10.3390/axioms11030089

[26] https://gepa.enerji.gov.tr/pages/58.aspx (Access: 01.12.2024).

[27] Yazdani, M., Zarate, P., Kazimieras Zavadskas, E. & Turskis, Z. (2019). A combined compromise solution (CoCoSo) method for multi-criteria decision-making problems. *Management Decision*, 57(9), 2501-2519. https://doi.org/10.1108/MD-05-2017-0458

[28] Tzeng, G. H., & Huang, J. J. (2011). Multiple attribute decision making: methods and applications. CRC press.

[29] Zavadskas, E. K., Turskis, Z., Antucheviciene, J., & Zakarevicius, A. (2012). Optimization of Weighted Aggregated Sum Product Assessment. *Elektronika Ir Elektrotechnika*, 122(6), 3-6. https://doi.org/10.5755/j01.eee.122.6.1810

[30] Stević, Ž., Pamučar, D., Puška, A., & Chatterjee, P. (2020). Sustainable supplier selection in healthcare industries using a new MCDM method: Measurement of alternatives and ranking according to COmpromise solution (MARCOS). Computers & industrial engineering, 140, 106231. https://doi.org/10.1016/j.cie.2019.106231