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An MCDM- Based Approach for Renewable Energy Planning in Iran

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Original Article

Abstract. In selecting appropriate energy technologies for various regions of Iran, policymakers should consider the geographical diversity of the territory, which provides remarkable renewable energy sources. Any investment in renewable energy technologies without proper assessment wastes financial resources and may also increase the possibility of losing social capital and public confidence in renewable energy promotion policies. Multiple criteria methods are appropriate for assembling and handling a wide range of variables evaluated in different ways, thereby offering valid decision support. This research aims to develop a model to rank and classify potential renewable energy technologies based on multiple criteria methods. Five potential alternatives were considered in terms of four general clusters - technical, environmental, financial, and social - and all decision-makers were also classified into these groups. After a comprehensive literature review, PROMETHEE was selected as an appropriate Multi-Criteria Decision-Making (MCDM) method. The model was built using a Group Decision Support System (GDSS) procedure incorporating theoretical and empirical data from governmental and academic resources. Common and specific parameters were accounted for based on each group's proficiency. In the early stage, 30 criteria were investigated. Finally, individual and group evaluations were carried out, and differences between potential alternatives were determined. As a result, they were prioritised in order of preference, with micro hydropower, wind, and solar emerging as the best alternatives, respectively.

Keywords: *Decision Making; Evaluation Criteria; MCDM; Planning; PROMETHEE; Policy Making; Renewable Energy*.

1. INTRODUCTION

Iran has some regulations in the energy sector but lacks a comprehensive energy policy in practice. Over the past few decades, some rules and regulations have been implemented to solve the existing problems. However, each subsector has plans which may not align with those of other subsectors. Demand for energy in Iran as a developing country is rapidly rising. The energy scenario shows that by 2030, the total energy demand will almost double. In a few decades, the increasing trend of domestic demand for fossil fuels would lead to an exhaustion of conventional energy sources, particularly oil. Therefore, changing Iran from an oil-exporting to an oil-importing country.

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As a result, although energy security may not be an urgent problem for Iran, it will soon become an issue (Moshiri & Lechtenbohmer, 2015). To provide sustainable development in a society, it is necessary to have abundant energy sources.

These energy sources should be obtained at a reasonable cost and used for all requirements of society without causing any negative social effects (Çolak & Kaya 2017). According to the Iran National Energy Strategy 2040, approved by the Council of Ministers in 2017, increasing the proportion of gas in electricity generation is deemed unattainable. Instead, the focus is placed on two crucial objectives: enhancing the efficiency of existing power plants and sourcing electricity from renewable resources. Consequently, the shift from conventional energy sources to renewable energy is inevitable in Iran's future energy strategies.

Energy planning has multiple objectives, definitions, and criteria, making it more difficult to attain a sustainable system. Traditional single-objective decision-making, which is concerned with either maximising or minimising a particular element, remains beneficial only in studying small systems. Thus, an adequate planning system which considers necessary political, social, economic, and environmental aspects is essential to overcome the rising demand for energy while retaining the vision of sustainable development (Kumar et al., 2017). In such cases, decision analysis plays a vital role in designing these systems by considering various criteria and objectives even at disintegrated levels of electrification. Therefore, the analysis and evaluation of renewable energy technologies have received more attention in the politics of different countries and the scientific literature (Siksnelyte-Butkiene et al., 2020). Multi-Criteria Decision Making (MCDM) methods often rank the concrete alternatives from the best to the worst based on multiple-dimension conflicting criteria. These methods enable evaluating alternatives and making a selection among them. Although selection between renewable energy alternatives is seen as an easy process, it is necessary to assess in terms of technical, economic, technological, socio-political, and environmental aspects (Çolak & Kaya, 2017).

These tools are becoming popular in the field of energy planning due to the flexibility they provide to the decision-makers to consider all the criteria and objectives simultaneously while making decisions (Kumar et al., 2017). Literature shows that there is still a wide range of research space in employing the MCDM method to solve renewable alternative evaluation problems. Therefore, it is expected that in the future, more MCDM and hybrid methods will be applied to studying renewable energy planning (Shao et al., 2020). It is important to understand whether the interactions between different criteria can be measured when evaluating alternative renewable energy sources (Zhang et al., 2020).

On the other hand, it is crucial to carry out the current research at the national level. Despite the absence of a comprehensive renewable energy plan, the Iranian government is actively undertaking numerous initiatives to promote the development of renewable energy. One such initiative is the implementation of a feed-in tariff system, which guarantees the purchase of electricity from eligible renewable energy generators. In this system, electricity purchased from different renewable energy sources is paid for in varying amounts. These incentives serve as a reflection of the government's perception of each alternative’s importance. Furthermore, in times when governments face challenges in meeting the country's electricity demands, particularly during peak periods, they consider the renewable energy development program and allocate resources for specific types of facilities. As an example, the government has recently introduced incentives to promote the establishment of 15,000 megawatts of solar power plants.

It is crucial to prioritise renewable resources based on scientific principles and specific evaluation criteria. This evaluation should not only consider the potential of renewable resources, but also take other influential factors into account, such as capital requirements, domestic technologies, and the cost of electricity production. Now, a pertinent question arises regarding the scientific evaluation criteria for determining the priority of renewable energy sources in Iran. Given the country's limited resources, should investing in solar power plants be prioritised?

This paper addresses two distinct research gaps at both the global and the local level. There is still a worldwide necessity to employ MCDM methods for effective renewable energy planning. Additionally, there is a need for a systematic approach to evaluate and prioritise various renewable energy options in Iran while considering multiple criteria. The significance of this study lies in its ability to provide a structured, comprehensive, and objective approach to decision-making. By considering multiple criteria, involving stakeholders, optimising resource allocation, and guiding long-term planning, this study supports the transition towards a sustainable energy system and facilitates the realisation of renewable energy goals at the global scale.

The present research offers a valuable and practical contribution to achieving a sustainable energy system by conducting an in-depth examination of the various renewable energy options in Iran while taking different aspects into account. Additionally, it puts a comprehensive MCDM framework forward that is specifically designed for renewable energy planning. These contributions have the potential to advance the field of renewable energy planning by providing decision-makers with a systematic approach to evaluate and prioritise renewable energy alternatives based on various criteria and stakeholder preferences. Additionally, they can provide insight into the practical challenges and considerations involved in executing renewable energy projects. Furthermore, the study proposes a comprehensive MCDM framework specifically tailored for renewable energy planning. This framework offers a structured approach to assess and prioritise different renewable energy options based on multiple criteria. It allows stakeholders to make well-informed decisions by considering the trade-offs between different criteria.

1.1 Objectives for Renewable Energies

As part of its ongoing commitment to sustainable development, Iran intends to acquire technologies related to renewable energy production. According to the objectives outlined in the 20-year vision, Iran should become a regional power in terms of the production and use of renewable energy resources by 2025. The objectives envisaged in the plan are as follows (Moshiri & Lechtenbohmer, 2015):

1. Electricity generated from renewable energy sources will account for 10% of the total electricity generated in the country.
2. Ensuring energy security through diversifying energy resources in the energy basket.
3. Achieving environmental conservation through reducing ecological pollution.
4. Improving policy-making strategies regarding renewable energy resources.
5. Providing financial support for research and development to increase technical knowledge and to improve the competitiveness of renewable energy sources vis-a-vis other sources of energy.

According to Article 50 of the Sixth Development Program, the government is obligated to increase the share of renewable and clean energy with priority investment from the non-governmental sector (domestic and foreign), utilising internal capacity to generate at least 5% of the country's electricity capacity by the end of the year 2023.

Furthermore, based on the approval letter of the Council of Ministers in 2015, ministries, institutions, government companies, non-governmental public institutions, banks, and municipalities must ensure that at least 20% of their buildings’ electricity consumption is generated from renewable sources for two years, based on the published list by the Ministry of Energy.

1.2 Application of MCDM in Renewable Energy Planning

Multi-Criteria Decision Making (MCDM) methods can prioritise renewable sources and present policymakers with a reliable solution for strategy development. MCDM methods are becoming increasingly popular for energy decision-making due to their capability to deal with complex decision processes, in the face of multiple and conflicting evaluation criteria, and different stakeholders with different preferences, uncertainties, and distinct time frames (Antunes & Oliveira, 2014).

Adopting and choosing renewable energy sources is a multidimensional decision-making process that involves several different characteristics at different levels: economic, technical, social, and environmental (Diakoulaki & Karangelis, 2007). In that regard, multi-criteria analysis appears to be a suitable tool to merge and analyse all perspectives concerning the decision-making process, by establishing a relationship between all alternatives and factors that influence the decision. It can provide a technical-scientific decision-making support tool that can justify its choices clearly and consistently in the renewable energy sector (Cavallaro, 2010).

1.3 Appropriate MCDM Method

Selecting a Multi-Criteria Decision Analysis (MCDA) method implies selecting a compensation logic (Hämäläinen & Karjalainen, 1992). Numerous problems with applying MCDA methods in renewable energy planning have been found. The review of MCDA methods demonstrates that there is no single method that can perform perfectly in all identified attributes (Abu-Taha, 2011). The literature review indicates that there are several examples of how different MCDA methods have been employed for energy planning (Karbin & Rashidi Komijan, 2016). However, all of the studies considered different aspects of energy networks with only one energy carrier, electricity, being the most common. Moreover, they were conducted on a fairly large scale, such as a regional or national level, similar to the present study.

Furthermore, there are often multiple decision-makers (DMs) responsible for these systems, each with conflicting objectives that they would like to include in planning. The choice of MCDA methods is as important as the person using them. There are many possible explanations for these differences; the DM may not fully understand the method, or some methods may not be able to represent the DM's preferences validly (Abu-Taha, 2011). In addition, grouped evaluation indicators will facilitate the design of future studies (Siksnelyte-Butkiene et al., 2020).

Choosing a method can be a challenging task, and there are several criteria to consider (Schulz & Stehfest, 1984). One of the most important criteria is validity, i.e., whether the method measures what it is intended to measure. Different methods are likely to yield different results, so the method that most accurately reflects the user's values should prioritised. However, it is important to note that different people have different ways of thinking about and expressing values (Chatzimouratidis & Pilavachi, 2009). Therefore, the method that is the most valid for one DM may not be suitable for other DMs. Another crucial property is appropriateness, i.e., whether the method is compatible with the available data and can provide DMs with all the information they require. The MCDA method should also be user-friendly and easy to understand, even for non-experts. If the method's logic is not transparent, a DM may perceive the methodology to be a black box, leading to a lack of trust in the recommendations from the method. In such cases, applying the MCDA method would be meaningless.

The transition towards a decarbonised energy system like renewables is a complex and multifaceted policy problem that involves numerous stakeholders with different sets of objectives and priorities Therefore, having a good understanding of the following is vital for a successful energy transition strategy (Guðlaugsson et al., 2020):

- The interest and power of all relevant stakeholders or stakeholder groups within a specific energy system.
- Determining who is affected by the decisions, and who has the power to influence the outcome, i.e., other stakeholder groups.

An MCDM method for decision-making regarding renewable energy resources must address several specific aspects. Firstly, it should be compatible with the operationalisation of sustainability, as renewable energy development is a sustainable planning issue. Secondly, since the decision-making process involves multiple stakeholders, the selected technique should be suitable for grouped evaluation and capable of modelling the preferences of decision-makers. Additionally, the technical features of the method should include input capabilities, interaction with the method, and the hierarchy of scale issues. While all these technical features are important, from the perspective of the decision-maker, the interaction with the method plays a key role. This interaction reflects the number and nature of parameters that the decision-maker needs to assess to become familiar with the model. Lastly, practical aspects should also be considered. The technique should be easy to use, able to support a large number of decision-makers and must be able to handle numerous criteria and alternatives. Furthermore, the parameters of the technique should be directly interpretable, allowing for a clear understanding of their implications (Polatidis et al., 2006; Karbin & Rashidi Komijan, 2016).

Various MCDM techniques, including the Analytic Hierarchy Process (AHP), TOPSIS, and ELECTRE, are considered potential solutions for this issue, depending on the unique demands and attributes of the decision problem. A previous evaluation has been conducted to compare different MCDM methods and identify the most suitable approach for prioritising renewable energy sources in a specific scenario. PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluation) is often considered more suitable among MCDM methods for prioritising renewable energy sources due to the following reasons (Karbin & Rashidi Komijan, 2016):

- Flexibility: PROMETHEE is a flexible MCDM method that allows decision-makers to incorporate various criteria and preferences into the decision-making process. In the context of renewable energy sources, there are multiple criteria to consider, such as cost, environmental impact, technological feasibility, and social acceptance. PROMETHEE enables the integration of these criteria and the exploration of different scenarios and preferences.
- Pairwise comparison: PROMETHEE utilises pairwise comparisons to evaluate and rank alternative solutions. Decision-makers can systematically analyse the relative importance of different renewable energy sources concerning each criterion. This pairwise comparison approach helps in capturing the decision-makers' preferences and their perception of the trade-offs between different criteria.
- Outranking concept: PROMETHEE employs the concept of outranking, which allows for a more nuanced analysis of alternatives. It considers not only the relative performance of alternatives but also their proximity to each other in terms of the criteria. The outranking concept enables a more comprehensive assessment of renewable energy sources and their potential for prioritisation.
- Visual representation: PROMETHEE provides visual representations, such as preference graphs and dominance matrices, to aid decision-makers in understanding the results and making informed choices. These visual representations help in interpreting the outcomes of the analysis, facilitating effective communication and consensus-building among stakeholders involved in the decision-making process.

- Transparency and interpretability: PROMETHEE provide transparent and interpretable results by offering preference indices and net flows that quantify the relative performances of alternatives. This transparency helps the decision-makers to understand the reasoning behind the rankings and facilitates the identification of critical criteria and their impact on the prioritisation process.

As mentioned previously, this method is more suitable where stakeholders' participation is required for decision-making (Talukder & Hipel, 2021). The success of the PROMETHEE method comes from its mathematical features and ability to solve uncertain problems. The method is one of the most suitable for assessing renewable energy technologies. However, it is only suitable for experts because the computation process is very long and complicated (Siksnelyte-Butkiene et al., 2020).

2. SETTING UP THE METHOD

2.1 Briefing the Decision Makers about the Procedure

To evaluate priorities for renewable energy development, a group decision-making method was adopted. Sixteen experts from different sectors including government, private companies, scientific associations, research institutes, and universities were involved in evaluating each alternative. DMs were classified into four groups based on their background: technical, economic, social, and environmental.

This preliminary stage is for knowledge acquisition and problem structuring. Its purpose is to build an evaluation matrix, that includes a set of potential alternative decisions and a set of criteria through which they will be evaluated. The procedure is extremely flexible at this stage. Individual opinions can be freely expressed, feedback can be provided at any time, additional steps can be considered, and some steps can be deleted.

It is usually recommended to hold at least one preliminary meeting to ensure contact between the DMs, and possibly some experts involved in the decision-making process. Depending on the characteristics of the decision problem, the researchers, as an accelerator, can meet with the decision-makers and experts together or individually. In the current study, some decision-makers and experts were able to meet together, while for others, meetings were conducted individually. During this step, an overall description of the problem was projected, and the available infrastructure was evaluated based on the information provided.

2.2 Proposing Alternatives

In this phase, decision-makers worked separately. All DMs were invited to formulate possible alternatives. For this purpose, they used a specific entry form. After giving a name to their proposal, the DM fills out a complete description of the alternative. Each DM could introduce one or more proposals. The nature of the alternatives depends on the nature of the renewable energy technologies, such as equipment, marketing strategies, R&D projects, production schemes, long-term strategies, and macroeconomic policies.

At this step, five possible alternatives were proposed that reflected the locally more applicable renewable energy options. These alternatives are presented as follows:

- Solar photovoltaic (PV): Photovoltaic cells convert sunlight directly into electricity. It is fuel-free, reliable, silent, and durable. PV panels can be mounted on a building's roof or erected on the ground. In Iran, several local installers are established with the government's support and installations are running successfully.

- Wind power: Wind produces electricity by turning the blades of a wind turbine (similar to a windmill). It is fuel-free, reliable, and can produce large amounts of power. Wind is the world's fastest-growing energy source. Currently, there are limited domestic companies, but some representative agencies are working in the country.
- Geothermal: Geothermal power uses natural heat from the Earth's core, while ground thermal recovers the heat from the surrounding area underground. The soil accumulates natural heat, either from the atmospheric difference in surface temperature or from the Earth's core. Once the heat is tapped and recovered, can be used to warm buildings and generate electricity. Currently, a local industry exists for ground source thermal conversion.
- Micro-hydro: Water (hydro) power is a system in which flowing water is used to turn a water turbine, generating electricity through the coupled generator. They seldom require the construction of a dam, except for a few isolated locations where the value of electricity is very high due to the lack of competing power options. Micro-hydro projects can be less than 100 kW in capacity for small off-grid and on-grid applications. In many parts of the world, the opportunities for furthering hydro developments are dwindling and smaller sites are being examined as alternatives. As a result, the potential of the micro-hydro market significantly grows. Several installed projects have proven to be economically viable and this technology is fully localised.
- Biomass heating systems: Biomass heating systems burn organic matter such as wood chips, agricultural residues, or municipal waste to generate heat for buildings, whole communities, or industrial processes. More sophisticated than conventional woodstoves, they are highly efficient heating systems, achieving near complete combustion of the biomass fuel through control of the fuel and air supply, and often incorporating automatic fuel handling systems. Biomass heating systems have a higher capital cost than conventional boilers and need proficient operators. Balancing this, they can supply large quantities of heat on demand with very low fuel costs, depending on the provenance of the fuel.

2.3 Selecting the Decision-Making Criteria

The provision of adequate and reliable energy services at an affordable cost, in a secure and environmentally benign manner, and conforming to social and economic development needs, is an essential element of sustainable development. The main criteria used in energy decision-making studies may be broadly categorised as reflecting technical, economic, environmental and social axes of evaluation (Antunes & Henriques, 2016). In the past few decades, the research on the sustainability of renewable energy mainly focuses on the assessment of sustainability in energy systems, economy, society, environment and technology (Wang & Zhan, 2019).

A holistic approach is required for the development of energy systems that can help solve broader problems associated with the essential linkages between the energy systems, the environment, and the socio-economic development. Thus, the prerequisite for selecting the best course of action is as follows (Antunes & Henriques, 2016):

a. Considering the evaluation criteria and methods that can perform a thorough assessment of the energy decisions at stake (or a subset of alternatives for further screening).

b. Ranking the alternatives or assigning them to categories of merit.

c. Informing DMs about their integrated performance and monitoring their impacts on the environment and the socio-economic context.

Upon gathering information regarding potential alternatives, the group must confront the challenge of selecting the most optimal option(s). Typically, there is a lack of consensus on the most favourable solutions due to the varying preferences of DMs. On one hand, each DM is faced with individual conflicts stemming from the multi-criteria nature of renewable energy technologies, on the other hand, conflicts arise between the DMs. The implementation of a Group Decision Support System (GDSS) procedure has proven effective in managing these conflicts. To this end, an open discussion phase was initiated to establish the possible evaluation criteria.

Numerous scholars have considered the sustainability indicators of energy planning. Some indicators and related criteria focus on the delivery of essential energy services to reduce poverty and improve living conditions. However, other indicators focus more on environmental effects. when deciding on appropriate policies, it is important to take not only the economic but also the social and environmental issues into account (Eurostat, 2008). The application of energy indicators in developing countries and countries with economies in transition, highlighted in the national case studies of Brazil, Cuba, Lithuania, Mexico, Russia, Slovakia and Thailand, is summarised in technical, economic, social and environmental dimensions (Vera & Langlois, 2007). Since energy planning has multiple objectives, an adequate planning system which considers the necessary political, social, economic, and environmental aspects is essential to overcome the rising demand for energy while retaining a vision of sustainable development (Antunes et al., 2014; Kumar et al., 2017; Siksnelyte-Butkiene et al., 2020).

Therefore, the indicators employed in this research constitute a core set of energy indicators for sustainable development (EISD) with corresponding methodologies and guidelines useful to policymakers, energy analysts, and statisticians in the four above-mentioned dimensions. The responsibility of DMs was to carefully select, assess, and assign appropriate weightage to indicators that align with the specific circumstances of Iran, thereby facilitating sustainable development.

The process employed in this particular stage mirrors that of the proposing alternatives stage, wherein both individual and general criteria were considered. General criteria refer to those criteria that are unanimously agreed upon by all members of the group, while individual criteria pertain to criteria that are considered by one or a few members, without any consensus. An evaluation table was presented, encompassing all evaluation criteria, ranging from individual to general criteria.

The criteria with real and objective data for evaluation within the country, and significant impacts on the prioritisation of renewable resources, were directly included in the final criteria table. Among the remaining criteria, which were either of lesser priority or lacked available data during the study, a selection of limited criteria was made based on the opinions of the decision-makers. Consequently, during this stage, all decision-makers were confronted with an evaluation table comprising a multitude of possible options and evaluation criteria. Ultimately, for all 30 criteria viewed from four dimensions, whether they had objective data for comparison or not, the evaluation table was finalised in such a manner that allowed each decision-maker to choose their desired criteria simultaneously. An agreement was reached among the decision-makers regarding ten final criteria as shown in Table 1.

Table1 . Final criteria

Row	Code	Abbreviation	Title	Definition
1	C1	GC	Power Generation Capacity - (MW)	The amount of electricity generation by the power plant.
2	C2	DTC	Domestic Technical Capability	Also known as the local technical know-how is a qualitative assessment of the complexity of the technology and the capacity of local actors to ensure appropriate support for its production, installation and maintenance.
3	C3	GD	Geographical Diversity	Namely concerning energy production mix, technology, or supply sources.
4	C4	DIS	Dispatchability	Grid connecting for peak load response is technology's ability to respond promptly to large variations in demand.
5	C5	IC	Investment Cost - (USD/kWh)	Including the purchase of mechanical equipment, technological installations, construction of roads and connections to the national grid, engineering services, drilling, and other incidental construction work.
6	C6	MC	Annual Maintenance Cost - (USD/kWh)	Wages and the funds spent for energy, products and services, and preventive and corrective maintenance work.
7	C7	UL	Useful Life	A period that a power plant can generate electricity in a commercially competitive manner compared to other production technologies.
8	C8	EMP	Employment - (MW/capita)	Job creation encompasses both the direct and indirect employment opportunities generated by power plants, as well as the social impacts that arise as a result.
9	C9	CO	CO Emission - (Mt CO2-eq)	Includes acidification and different types of emissions (CH4, CO2, NOx, SO2, SOx, etc.), effects on the natural environment, and photochemical ozone creation.
10	C10	LR	Land Requirement - (km2·a)	Includes the number of land-use changes, visual impacts, local pollutants, and wastes.

Researchers directly evaluate the data-driven criteria. The information necessary to evaluate the other criteria was also gathered based on the DMs' opinions. All the DMs are thus facing the same evaluation matrix that includes "i" as possible alternatives, and "k" as evaluation criteria. Each DM can request to enter I, based on his/her evaluations, in the table. As with most multi-criteria decision aid methods, the PROMETHEE method requires numerical evaluations. Qualitative scales such as very good, good, average, bad, and very bad, were transformed into numerical scales such as 5, 4, 3, 2, 1, or a more sensitive scale ranging from 0 to 10, or 0 to 100. All evaluations are expressed in their units. For instance: US$ for investment cost, Mega Watt for power production, and number of people for employment. All scale effects are taken into account by the PROMETHEE methods.

Once the set of criteria and the alternatives have been selected, the payoff matrix is built as shown in Table 2. This matrix tabulates, for each criterion–alternative pair, the quantitative and qualitative measures of the effects produced by that alternative for that criterion. The matrix may contain data measured on a cardinal or an ordinal scale. The necessary data to assess the chosen criteria were obtained from national documents, reports, articles, and international references. The group members ensured the validity of the data and reached a consensus among themselves.

Table2 . Evaluation matrix

Alternative	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Solar	50	Bad	Very Good	Bad	3650	2.55	25	18.2	18	849
Wind	155	Bad	Good	Bad	2500	1	20	18.3	4.8	638
Micro-hydro	750	Bad	Average	Average	5200	0.9	60	22.9	1.5	35
Biomass	100	Average	Bad	Good	5000	1.1	20	13.21	3.7	18880
Geothermal	101	Very Bad	Very Bad	Good	3425	0.95	27	11.4	4.5	655

2.4 Individual Evaluation

The proposed alternatives must now be evaluated. Weighting the criteria is an important aspect and depends on the decision-makers' expertise. This method is suitable where stakeholders' participation is required for decision-making (Talukder & Hipel, 2021). The GDSS-PROMETHEE procedure includes an individual evaluation singe, which is performed by each DM separately, and a global one for the whole group. To achieve better results and avoid unnecessary conflicts, the individual evaluation stage is separately performed within the four mentioned groups.

Once the alternatives and the evaluation criteria have been identified, the evaluation process can start. For this purpose, the basic PROMETIIEE methodology is used. Firstly, each DM needs to define additional information: information between the criteria that will be given by weights of relative importance, and information within the criteria that will be given by preference functions.

For the weights of the criteria, the following equation was applied. Let DM_r (r=1,2,3…R) be the R decision makers and the weights associated with the k criteria by DM_r. There is no objection to considering notified weights.

$$w_1^r, w_2^r, \dots, w_j^1, \dots w_k^r \qquad \left(\sum_{j=1}^{k} w_j^r = 1 \right) \tag{1}$$

If decision maker DMr considers that some criteria are not relevant to him, he will assess weights equal to zero to these criteria. This means that these criteria will not be considered in his analysis. Consequently, although every DM group is facing the same evaluation matrix, the number of active criteria considered by each of them can vary.

The DMs are invited to assign individual weights expressing the relative importance of each criterion. Each DM is not necessarily interested in the 10 criteria. Non-relevant criteria assumed as 0 and each DM group was allowed to maximise or minimise each criterion. The individual choices are shown in Table 3.

Table3 . Min/Max options and weights

Group	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Technical	Max 3	Max 2	Max 2	Max 1	Min 1	0	Min 1	0	0	0
Economic	0	0	0	0	Min 3	Min 1	Min 1	Max 1	0	0
Social	0	Max 1	Max 1	0	0	0	0	Max 1	0	Min 1
Environmental	0	0	Min 1	0	0	0	0	Min 1	Min 1	Min 1

The weights given here are not named (this is automatically done by the software). Each DM is not interested in all the criteria. We notice that the selected criteria are completely in agreement with the concerns of the DMs. For instance, a member of the environmental group wants to minimise geographical diversity potential to reduce the environmental impacts, while a member of the technical group wants to maximise it to create more opportunities for renewable technology development. The aforementioned situation describes an extreme example, but it illustrates how having opposite points of view can generate strong conflicts between the DMs.

According to the PROMETHEE procedure, a preference function must be associated with each criterion for pairwise comparisons. Therefore, we have:

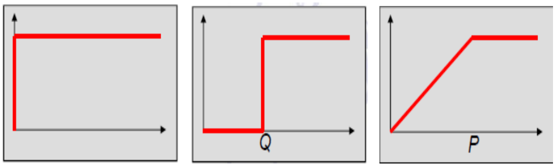
$$p_j(a,b)=G_j\left[F_j(a)-F_j(b)\right] \tag{2}$$

$$0\leq P_j(a,b)\leq 1 \tag{3}$$

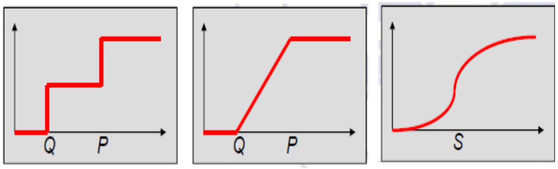
Where the preference function is associated with criterion F_j (.), and G_j is a non-decreasing function of the deviation between F_j (a) and F_j (b). If F_j (.) is a criterion to be maximised, we will have:

$$\begin{cases} G_j[f_j(a)-f_j(b)]=0 \quad \text{if} \quad f_j(a)<f_j(b) & \text{no preference} \\ G_j[f_j(a)-f_j(b)]\sim 0 \quad \text{if} \quad f_j(a)>f_j(b) & \text{weak preference} \\ G_j[f_j(a)-f_j(b)]\sim 1 \quad \text{if} \quad f_j(a)>>f_j(b) & \text{strong preference} \\ G_j[f_j(a)-f_j(b)]=1 \quad \text{if} \quad f_j(a)>>>f_j(b) & \text{strict preference} \end{cases} \tag{4}$$

The preference functions enable translating the deviations observed on a specific criterion into degrees of preference independent of its scale. To facilitate the selection of preference functions, six basic types are proposed in Figure 1. In each case, the preference function depends on two parameters maximum, with a clear economic significance (indifference and/or preference thresholds).



Usual U-shape V-shape



Level Linear Gaussian

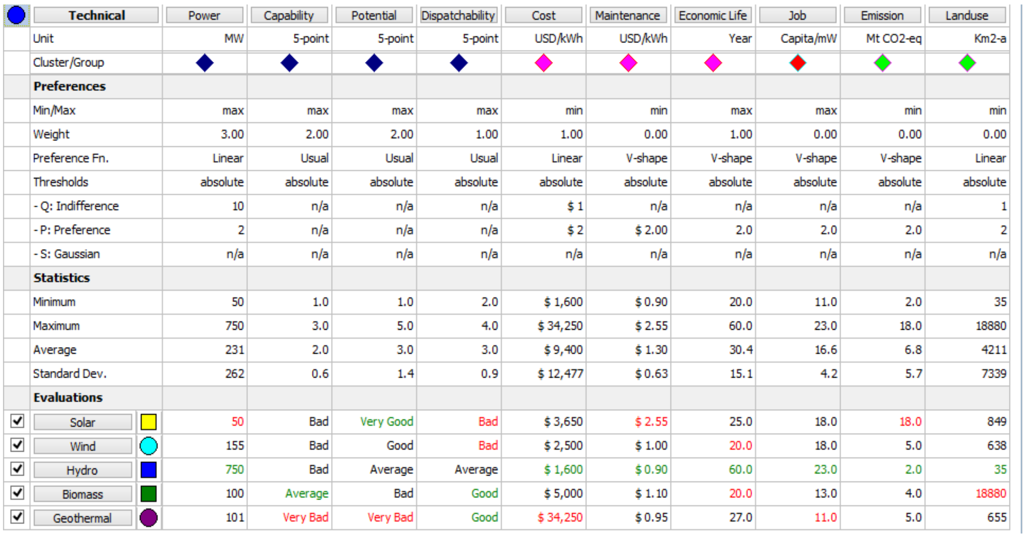
Figure1 .Different types of preference function

In this step, the researcher helps the DMs to select the preference functions. As each DM is facing the same criteria (although the associated weights could be different), the selection of the preference functions can take place globally in an 'open-discussion' phase. The Usual preference function is very simple. It can be the right choice for a criterion with a few very different evaluations. That is often the case for qualitative criteria. For example, this choice would be appropriate for a 5-level qualitative scale and therefore it was used for criteria 2, 3, and 4. The V-shape preference function is a special case of the Linear preference function where the Q indifference threshold is equal to 0. Therefore, it is well suited for quantitative criteria like criteria 6, 7, 8, and 9 in which even small deviations should be accounted for. The Linear preference function which is the best choice for quantitative criteria when a Q indifference threshold is existed was suitable for the rest of the criterion. Finally, the following table was made:

Table4 . Preference function for each criterion

Criterion	Name	Type	p, q, s-values
C_1	GC	5	q=10 ، p=2
C_2	DTC	1	-
C_3	GD	1	-
C_4	DIS	1	-
C_5	IC	5	q=1 ، p=2
C_6	MC	3	p=2
C_7	UL	3	p=2
C_8	EMP	3	p=2
C_9	CO	3	p=2
C_{10}	LR	5	q=1 ، p=2

In this case, all the preference functions were the same for all DMs. However, there is no objection to treating this step individually. At the end of this step, each DM group disposes of the evaluation matrix completed with the preference functions and the weights that they have defined. Then according to the PROMETHEE-GAIA methodology, the following quantities can now be computed for each DM group:



●	Technical	Power	Capability	Potential	Dispatchability	Cost	Maintenance	Economic Life	Job	Emission	Landuse
	Unit	MW	5-point	5-point	5-point	USD/kWh	USD/kWh	Year	Capita/mW	Mt CO2-eq	Km2-a
	Cluster/Group	◆	◆	◆	◆	◆	◆	◆	◆	◆	◆
	Preferences										
	Min/Max	max	max	max	max	min	min	max	max	min	min
	Weight	3.00	2.00	2.00	1.00	1.00	0.00	1.00	0.00	0.00	0.00
	Preference Fn.	Linear	Usual	Usual	Usual	Linear	V-shape	V-shape	V-shape	V-shape	Linear
	Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute
	- Q: Indifference	10	n/a	n/a	n/a	$ 1	n/a	n/a	n/a	n/a	1
	- P: Preference	2	n/a	n/a	n/a	$ 2	$ 2.00	2.0	2.0	2.0	2
	- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Statistics										
	Minimum	50	1.0	1.0	2.0	$ 1,600	$ 0.90	20.0	11.0	2.0	35
	Maximum	750	3.0	5.0	4.0	$ 34,250	$ 2.55	60.0	23.0	18.0	18880
	Average	231	2.0	3.0	3.0	$ 9,400	$ 1.30	30.4	16.6	6.8	4211
	Standard Dev.	262	0.6	1.4	0.9	$ 12,477	$ 0.63	15.1	4.2	5.7	7339
	Evaluations										
☑	Solar 🟨	50	Bad	Very Good	Bad	$ 3,650	$ 2.55	25.0	18.0	18.0	849
☑	Wind ●	155	Bad	Good	Bad	$ 2,500	$ 1.00	20.0	18.0	5.0	638
☑	Hydro 🟦	750	Bad	Average	Average	$ 1,600	$ 0.90	60.0	23.0	2.0	35
☑	Biomass 🟩	100	Average	Bad	Good	$ 5,000	$ 1.10	20.0	13.0	4.0	18880
☑	Geothermal ●	101	Very Bad	Very Bad	Good	$ 34,250	$ 0.95	27.0	11.0	5.0	655

Figure 2. Final evaluation matrix for each DM group

At the end of this step, the individual evaluation and GAIA analysis for each DM was carried out. The difference between any two potential alternatives can be determined as follows:

$$\pi^r(a,b) = \sum_{i=1}^{k} p_j(a,b)\, w_j^r \qquad \forall a,b \in A \tag{5}$$

Where π(a,b) of a over b (from zero to one) is defined as the weighted sum of $P_j(a,b)$ for factor j, and wj is the weight associated with factor j. In addition, π(a,b) expresses the degree to which a is preferred to b for all factors. Alternative a is facing (n−1) other alternatives in A.

$$\phi^{+r}(a)=\sum_{x\in A}\pi^{r}(a,x)$$
$$\phi^{-r}(a)=\sum_{x\in A}\pi^{r}(x,a) \qquad (6)$$

where ϕ+(a) and ϕ−(a) denote the positive and negative outranking flows for alternative a, respectively. In other words, ϕ+(a) expresses how alternative a is outranking all other (n−1) alternatives, while ϕ−(a) expresses how alternative a is outranked by all other alternatives.

In this step, the net outranking flow is computed and the potential alternatives ranking is as follows:

$$\phi^{r}(a)=\phi^{+r}(\mathrm{a})-\phi^{-r}(\mathrm{a}) \qquad (7)$$

where ϕ(a) denotes the net outranking flow of alternative a. The final ranking is obtained based on the principle that the higher the net flow, the more attractive the alternative would be.

2.5 Global Evaluation

The global evaluation and GAIA analysis for group decision-making are carried out so that all DMs are advised on potential conflicts. The last step of the process is summarised as follows:

$$\mathrm{P_i}(a,b)=F_i\left[\phi_i(a)-\phi_i(b)\right] \qquad i=1,\dots,m \qquad (8)$$

where $P_i(a,b)$ denotes the preference of alternative a to alternative b for DM_i.

$$\pi_{gdss}(a,b)=\sum_{i=1}^{m}P_i(a,b)w_i \qquad (9)$$

where $\pi_{gdss}(a,b)$ is defined as the weighted sum of $P_i(a,b)$ for all DMs, with w_i as the weight for DM_i. The PROMETHEE partial and complete rankings are obtained from the following equations:

$$\phi^{+}{}_{gdss}(a)=\frac{1}{m-1}\sum_{x=A}\pi_{gdss}(a,x)and\phi^{-}{}_{gdss}(a)-\frac{1}{m-1}\sum_{x\in A}\pi_{gdss}(x,a) \qquad (10)$$

$$\phi_{gdss}(a)=\phi_{gdss}{}^{+}(a)-\phi_{gdss}{}^{-}(a) \qquad (11)$$

where $\phi_{gdss}{}^{+}(a)$, $\phi_{gdss}{}^{-}(a)$ and $\phi_{gdss}(a)$ denote the positive, negative, and net outranking flows for alternative a, respectively.

3. ANALYSIS OF RESEARCH FINDINGS

One of the innovative measures that could play a significant role in enhancing the accuracy and speed of attaining results of the present survey is classifying decision-making groups into smaller groups based on primary criteria. Based on this classification, technical, economic, social, and environmental groups played significant roles in this survey. In the first step of decision-making, group members were able to develop options and criteria. Drawing on the potential of certain methods such as brainstorming and free discussion, they were able to develop a proper perception of the problem and pre-determined objectives. Moreover, the general decision-making process enables addressing problems of individualistic decision-making, points to the best agreed-upon option, and clarifies disagreements on different options.

3.1 Rating by The Technical Group

In terms of the number of selected criteria, the technical group demonstrated a greater impact than others. This group proposed more applicable renewable energy alternatives. Out of the 10 evaluation criteria, four were specified by this group, indicating their proficiency in addressing technical aspects. However, like other groups, the technical group was able to address other criteria during the final ranking phase. The weights are as follows: Production Capacity of power plant (30%), Internal Technical Capability (20%), Geographical Diversity Potential (20%), Dispatchability (10%), Investment Cost (10%), and Useful Economic Life of Power Plants (10%).

Based on assessments conducted by the technical group, the micro-hydro, solar, and biomass energy sources were ranked first to third, respectively. Geothermal energy received the last rank with the lowest score. Wind energy did not receive any negative or positive scores and ranked fourth as shown in Figure 3.

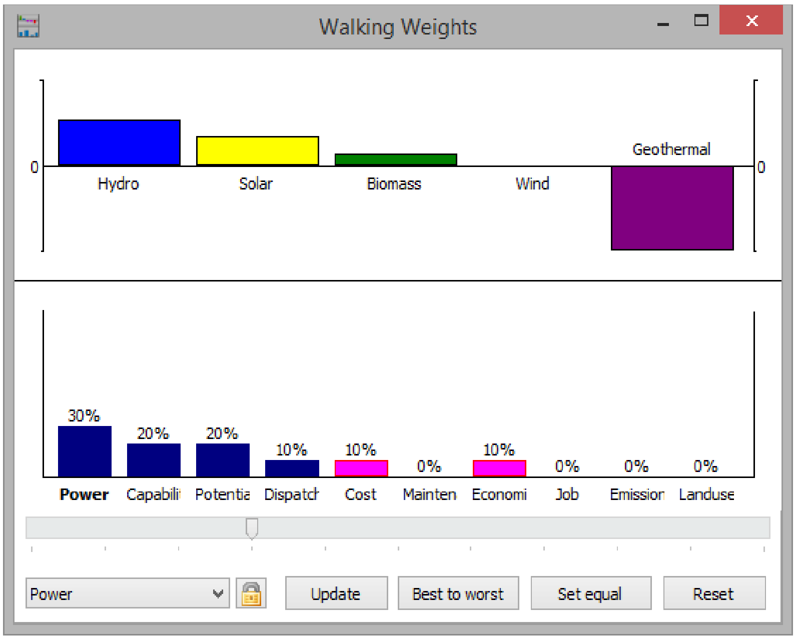


Figure 3. The technical group’s rankings

A technical comparison of the strengths and weaknesses of different alternatives revealed that micro-hydro was the only alternative that did not possess any weaknesses. Solar energy was the next best alternative, exhibiting favourable conditions in most criteria, except for dispatchability. Biomass was superior to both micro-hydro and solar energy but was considered less desirable due to negative scores in terms of investment cost, economic life, and geographical diversity potential. Wind energy received negative scores in two criteria, namely dispatchability and economic life. Finally, geothermal energy was the least preferred alternative due to low scores, particularly in terms of internal technical capability and geographical diversity potential.

3.2 Rating by The Economic Group

The economic group demonstrated the second highest level of influence based on three of the final criteria. Figure 4 illustrates that this group emphasised four criteria, with a weight of 50% assigned to the criterion of investment cost, and the remaining criteria (annual maintenance cost, economic life, and number of employments) scored 17%.

Based on the evaluations conducted by this group, micro-hydro and wind energy sources ranked first and second, respectively, and were introduced as suitable options. However, the other options failed to meet the minimum requirements to be recommended by this group, with geothermal power plants receiving the last rank. In terms of assessing the strengths and weaknesses of the options, it is noteworthy that the hydroelectric option had unique advantages and no weaknesses, and thus, it was ranked first due to its high scores for economic criteria. On the other hand, the economic life of power plants was the only weakness of the wind option, which assigned it the second rank. However, this option did not receive a high ranking in terms of other economic measures.

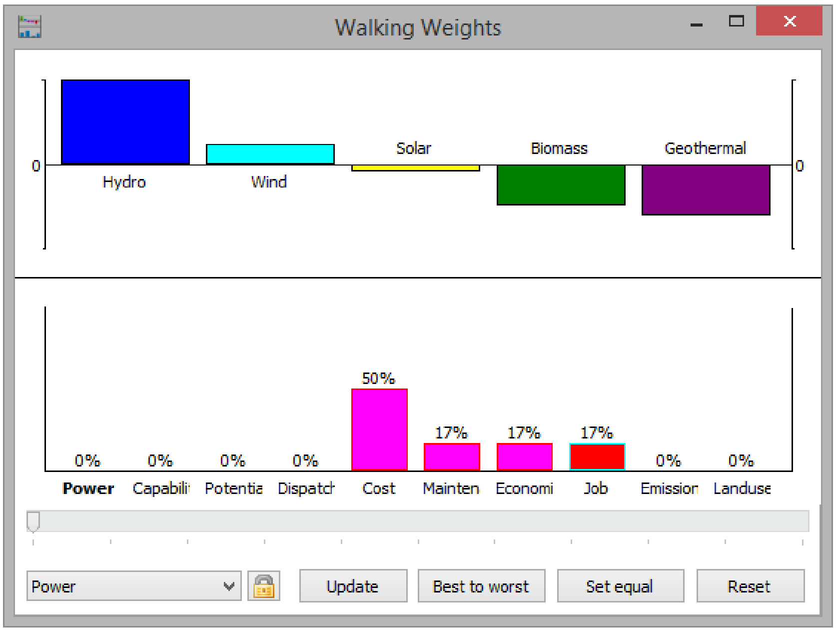


Figure 4. The economic group’s rankings

Despite having a relative edge over other options, the solar option received low scores for the criteria of employment, initial investment cost, and economic life of the power plant, which reduced its positive score. Additionally, the high annual maintenance cost made this option unacceptable. The geothermal option received the lowest rank due to significant weaknesses in terms of employment and initial investment cost.

3.3 Rating by The Environmental Group

As a result of incorporating two environmental criteria into the evaluation matrix, the environmental group received the third place in the ranking process. The figure below illustrates that this group emphasised four criteria, with each criterion assigned an equal weight of 25%. Based on the comments of this group, hydroelectric and wind energy resources were suggested as high-priority options, while other options failed to meet the minimum requirements. The geothermal and biomass options had relatively similar conditions, resulting in their low rankings. The solar option, located in the middle of the table, had a medium to low ranking.

Compared to the ranking of other groups, the hydroelectric option included in this group had a relatively high positive score. For this option, none of the selected criteria were identified as weaknesses, leading to its rise in ranking among other options. The emission of greenhouse gases was the sole weakness of the wind option. This weakness, coupled with low scores in other criteria, lowered this energy source’s rank to second place. If the development of solar power plants did not require extensive changes in land use and the emission of greenhouse gases, decision-makers could potentially prioritise this option over wind power plants. Similarly, geothermal power plants were ranked last due to their inability to satisfy the four criteria emphasised by the environmental group, resulting in a lack of noteworthy strength.

Figure 5.The environmental group’s rankings

3.4 Rating by The Social Group

Only one criterion from the total number of final criteria is delegated to the social group, resulting in the least impact on the ranking. As illustrated in Figure 6, this group emphasised four criteria, with each criterion assigned an equal weight of 25%. Based on their evaluations, the hydropower, wind, and solar energy sources were ranked first to third, respectively. The remaining two options failed to meet the minimum requirements, while geothermal received the most negative points.

Figure 6.The social group’s rankings

Upon examining the strengths and weaknesses of the options, it is evident that the geothermal option received the lowest score in all criteria emphasised by the social group, while hydroelectric received the highest score. The first and second options did not receive any negative scores in the criteria and exhibited no weaknesses in this regard. Due to its longer economic life, lower greenhouse gas emissions, and higher employment creation potential, hydropower received more positive points than wind and secured first position in the rankings.

As depicted in Figure 6, there was close competition between wind and solar alternatives, with solar being ranked third due to its larger land use and larger negative impacts on the areas where the power plants are located.

3.5 General Rating

Following the amalgamation of criteria weights by the decision-making groups, a new evaluation table was generated, wherein the initial investment cost and geographical diversity of potentials were allocated 17% of the total score, while power generation capacity, internal technical capacity, and employment rate were each assigned 12%. Land use changes were given 8%, and the ability to connect to the grid (dispatchability), annual maintenance cost, and greenhouse gas emissions were each given a score of 4%. As illustrated in Figure 7, micro-hydro received the highest score of 58% and was ranked first, followed by the wind option with a score of 20%, and the solar option with a score of 4%.

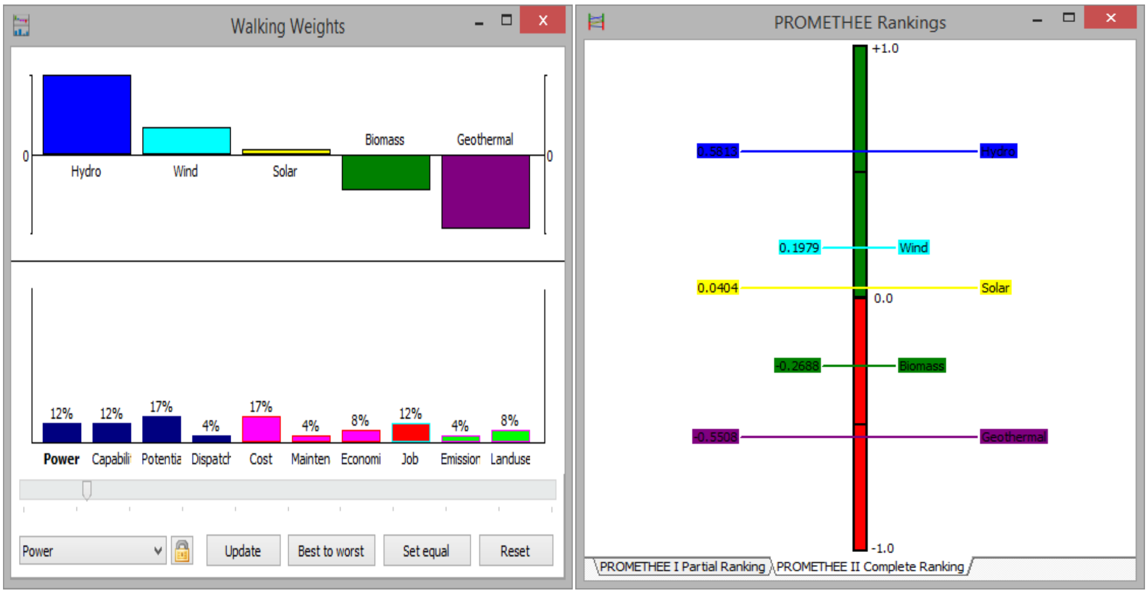


Figure 7.General rating results

Upon analysing the strengths and weaknesses of the alternatives, it was observed that micro-hydro did not receive any negative scores in any of the evaluation criteria, rendering it unique among all the alternatives. Conversely, the other options exhibited weak points in some criteria, with geothermal failing to attain the minimum expected score based on any criteria and retaining its ranking as the worst option.

CONCLUSION AND FUTURE RESEARCHES

The proposed MCDM model has been applied to analyse renewable energy alternatives in Iran. For this purpose, four main dimensions and 10 criteria were used to evaluate the determined alternatives concerning Iran's energy perspective. After considering the pertinent factors that impact the process of decision-making, it has been determined that the micro-hydro, wind, and solar alternatives hold the top three positions in the rankings. Given the considerable difference between the scores of hydroelectric energy sources and other options, it is imperative to focus on maximising the utilisation of energy reserves in surface water sources across the country. The present study indicates that focusing on the development of solar energy is not currently recommended, particularly from an economic and environmental perspective. However, considering the huge potential of the country in this field, and taking the possibility of the development of related technologies into account, solar energy could become one of the most significant replacements for fossil fuels in the future. Based on the positioning of the majority of the criteria on the right-hand side of the GAIA screen of the PROMETHEE method, and the alignment of several criteria, it can be inferred that there is no significant conflict among them. However, criteria 3 and 4, namely geographical diversity of potentials and dispatchability, may be in conflict with each other in certain instances. Therefore, it is recommended that future research reorganises the fourth criterion with an alternative.

The study has yielded a significant outcome in terms of identifying the most appropriate renewable energy options for specific contexts based on multiple criteria and stakeholder preferences. The strengths and weaknesses of each option have been highlighted, providing decision-makers with the necessary information to make informed choices that align with their goals and objectives. This outcome not only supports the transition towards a more sustainable energy system but also optimises the use of limited resources, minimises environmental impacts, and drives economic growth in the renewable energy sector. The evidence-based recommendations provided by the study enable decision-makers to select the most suitable renewable energy options, leading to more effective and efficient renewable energy planning and implementation. Policymakers can prioritise investments, subsidies, and infrastructure development based on the identified preferred renewable energy options, maximising the impact of limited resources, and accelerating the deployment of renewable energy technologies. The study's outcomes can provide valuable insight, evidence, and guidance for policymaking, enabling informed decisions, effective policies, stakeholder engagement, resource allocation, and sustainable energy planning. Policymakers can use the study's findings to shape regulations, incentives, and targets that promote the development and adoption of specific renewable energy technologies.

The Spatial Decision Support System is regarded as one of the most efficient interactive tools that assist decision-makers in semi-structured spatial problems. After development of evaluation criteria within the national scale, the next step is to assess their reliance on geographic regions. Using Geographic Information Systems, it will be possible to conduct spatial analysis and review the geographic distribution of the information. The combination of spatial decision-making systems with multi-criteria decision-making methods will produce highly valuable results.

It is important to acknowledge that the current study was conducted on a national scale. However, when it comes to local planning approaches, the outcomes may vary depending on the unique characteristics of the area. Hydropower is not a viable option in semi-arid regions due to the absence of permanent rivers and mountainous terrain. Therefore, it is advisable to adopt a zoning-based planning approach that considers the local geographical potential for regional planning. It is highly recommended to combine spatial decision support systems with MCDM for local-scale planning.

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