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EVALUATION OF GREEN ENERGY SOURCES: AN EXTENDED FUZZY-TODIM APPROACH BASED ON SCHWEIZER-SKLAR AND POWER AVERAGING OPERATORS

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Abstract. *To address the problem of green energy source selection, this paper proposes a novel decision-making framework using fuzzy-TOmada de Decisao Interativa Multicriterio (TODIM) method in an interval-valued intuitionistic environment. The proposed framework integrates the prospect theory approach with Schweizer-Sklar and power averaging operators to evaluate the green energy sources including solid waste, solar, tidal, carbon capture storage, hydrogen, marine, hydel, biogas, wind, concentrating solar, geothermal and biomass under the influence of nine conflicting criteria such as annual generation, capacity factor, mitigation potential, useful life, installation period, energy requirement, CO_2 emission, generating cost and operations and maintenance cost. The vagueness associated with the evaluations as well as biased evaluations is taken care of by Schweizer-Sklar and power averaging operators while TODIM method provides due consideration to the psychological behavior of the decision maker. Solar photovoltaic emerges as the best*

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energy source. Sensitivity analysis has also been performed to assess the robustness of the proposed decision-making framework.

Key words: *Green energy source selection, Fuzzy logic, Schweizer-Sklar and power averaging operators, TODIM, Sensitivity analysis*

1. INTRODUCTION

Green energy refers to energy that is produced from such sources that have minimal impact on the environment. These sources include solar, wind, hydro, geothermal, and biomass energy. Green energy is clean and sustainable. Green energy sources have emerged as a critical component of the world's energy mix. Unlike traditional energy sources such as coal, oil, and gas, green energy sources generate electricity without releasing harmful pollutants into the environment. These energy sources can be harnessed in a sustainable way to meet the growing energy demands of the world population. One of the major challenges in the globe at present is the massive and fast growth in world population, civilization, technology and progress which is correlated with the huge demand and excessive ingesting outline of energy, water, and food resources compared to energy production and limited natural resources such as land, water, minerals and fuel, etc. In addition to that, there are widespread distractions that caused negative effects on the environment which causes various trauma to the common people. The exhaustion and limitations of conventional energy sources are fostering more and more research into green, alternate and renewable energy sources [1]. Therefore, the need for a clean environment and energy, and economic security for sustainable development is becoming a real concern for the world communities in the last few years [2]. Decrease in ecological discharges, temperament of detrimental wastes, and espousal of green expertise and products are on the precedence list of sustainable planning. One of the primary advantages of green energy sources is their environmental sustainability. Unlike fossil fuels, which are finite and contribute to climate change, green energy sources do not emit greenhouse gases or other pollutants. This makes them an ideal solution for reducing our carbon footprint and mitigating the effects of climate change. To minimize dependence on fossil fuels, safeguard the environment, and reduce greenhouse gas emissions, switching from fossil to green energy is seen as an unavoidable trend. Green energy is also considered a long-lasting, affordable, and eco-friendly source of energy. Multinational enterprises have been at the forefront of advocating for the adoption of clean energy sources in many countries worldwide. The increasing number of businesses committing to the use of green energy and taking tangible measures to accelerate the transition to clean energy is a positive sign for global efforts toward achieving a greener future. As the sustainability concept emerges with increasing awareness about the environment, green energy sources take their positions in future energy planning worldwide for a long time. Green energy sources also offer numerous technological benefits such as reduced green- house emission, energy security and independence, low operating costs, community empowerment grid stability and resilience. The development of green energy technologies has spurred innovation and advancements in energy storage, grid integration, and other related fields. Advances in battery technology have made it possible to store solar and wind energy for use when the sun is not shining or the wind is not blowing. Grid integration technologies have made it possible to connect green energy sources to the power grid and manage their output in a more efficient way

[3]. The sources of green energy are numerous and diverse. The followings are the most often used for energy production: solid waste, solar, tidal, carbon capture storage, hydrogen, marine, hydel, biogas, wind, concentrating solar, geothermal and biomass. Green energy sources are being evaluated to prepare for the future is becoming more and more crucial in recent eras due to the presence of various conflicting criteria. Energy managers as well as policy makers are executing several policies and measures to ensure that renewable energy planning is of high environmental standards and conforms to the guidelines. The selection of green energy sources is important for mitigating climate change, improving energy security, protecting the environment, providing economic benefits, and driving technological innovation. The use of green energy sources can help to mitigate the impacts of climate change by reducing greenhouse gas emissions. Renewable energy sources do not produce the same level of carbon emissions as fossil fuels, which are a major contributor to climate change. Green energy sources can help to improve energy security by reducing reliance on imported fossil fuels. This can help to protect countries from energy supply disruptions, price volatility, and geopolitical risks. The use of green energy sources can provide economic benefits, such as job creation, increased energy independence, and reduced energy costs. As the cost of green energy technologies continues to decline, these benefits are becoming increasingly significant. The development and deployment of green energy sources can drive technological innovation and provide opportunities for new business models and market opportunities. However, the selection of technologies for green energy is a difficult transdisciplinary problem that mainly involves how well the technologies perform in response to several aspects, including environmental, social, technological, and economic ones. Multiple criteria decisions making (MCDM) models are thus essential for the selection of green energy sources because it allows decision-makers to take into account multiple criteria when evaluating and selecting energy sources. When selecting green energy sources, decision-makers need to consider a variety of factors, such as cost, energy efficiency, environmental impact, scalability, reliability, and availability. These criteria may be conflicting, and different stakeholders may have different priorities and preferences. MCDM methods are employed to address such complexities, facilitating the decision-making process in situations where traditional analytical approaches fall short [4].

2. Literature

Researchers have been investigating in wide array of decision-making problems associated with sustainable technologies using MCDM approaches such as selection of suitable site for charging station [5], selection of suitable site for installing floating photovoltaic system on dam reservoirs [6], healthcare supply chain resilience [7], assessment of management strategies in construction and demolition wastes [8], etc.

Studies on efficient green energy selection for sustainability planning were also discovered in the literature, focusing on various MCDM methods. Some of the highly motivated researchers in the field of green energy source selection are discussed in brief. Haralambopoulos and Polatidis [9] used Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE II) method to assess the renewable energy project in Greece based on factors like; fuel saved, return on investment, job creation, environmental and risk index. The ranking of renewable energy sources in Canada has been investigated by Nigim et al. [10] considering resource availability, financial viability, social benefit, educational potential, and ecological impact. Pohekar and Ramachandran [11] applied PROMETHEE method for selection of cooking energy substitution using renewable energy generation in India adopting factors like; chulha, improved chulha, kerosene stove, biogas stove, Liquefied Petroleum Gas (LPG) stove, microwave oven, electric oven, solar cooker. Patlitzianas et al. [12] utilized Ordered weighted averaging (OWA) method for the assessment of renewable energy producers in Greece using political, social, technological criteria and their sub-factors. As per the study conducted by Buchholz et al. [13], Multi-criteria analysis (MCA) is used for the evaluation of sustainable bioenergy projects in USA taking into account the stakeholder decision-making, application of qualitative data, uncertainty measures, ease of consumption, dynamic revolution, communication of decision process. Cavallaro [14] applied PROMETHEE method for the evaluation of solar thermal technologies for sustainable energy planning in Italy considering investment cost, operation & maintenance cost, mature technology, environmental impact, capacity factor. Chung and Lee [15] practiced in an integrated manner with Elimination and Choice Expressing Reality (ELECTREE) II, Evaluation of Mixed Data (EVAMIX) and Regime method for ranking of water management using renewable energy in the Republic of Korea using technical, environmental, economic criteria. Doukas and Psarras [16] used Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method for accessing renewable energy performance in Greece based on reduction in emission of greenhouse gases (GHG), environmental impact, contribution to job creation, local economic development, regional economic development, investment cost and adequacy of energy. Kahraman et al. [17] applied the fuzzy analytical hierarchy process (FAHP) for the evaluation of renewable energy alternatives in Turkey considering Technological, environmental, social, economic and energy criteria. Ren et al. [18] applied PROMETHEE method for the assessment of sustainable residential renewable energy systems in Japan based on various factors like: carbon dioxide (CO2) emission, cost of operation, investment cost and primary energy consumption. Assessment of sustainable energy in Greece is carried out by Tsoutsos et al. [19] based on investment, operation and maintenance cost, fuel savings, mature technology, safety ratio, energy supply, emission control, local development. Their study utilizes PROMETHEE I & II for evaluation purposes. Heo et al. [20] applied FAHP in Republic of Korea for the assessment of renewable energy factors considering technological, economic, environmental, market and policy criteria. Renewable energy assessment in Turkey was put forwarded by Kaya and Kahraman [21] using Vlsekriterijuska Optimizacija I Komoromisno Resenje (VIKOR) and AHP. The study considers technical, economic, environmental and social criteria. Shen et al. [22] applied FAHP for the evaluation of renewable energy sources in Taiwan based on energy price, security, energy supply, technical maturity and market size. A sustainable energy assessment for Canada is done by Reza et al. [23] considering factors like; resource depletion, losses in energy, management of waste, climate change, risks for the environment, performance cost, operation & maintenance cost, social acceptability. San-Cristóbal [24] applied VIKOR method for assessing renewable energy projects in Romania. Their study uses power, investment ratio, period of implementation, operational hours, useful life, cost of operation, costs associated with the maintenance and CO2 emissions as evaluating parameters. Davoudpour et al. [25] adopted AHP for the selection of renewable energy technology in Iran based on market competitiveness, technical factors and environmental factors. An integrated approach namely Benefits, Opportunities, Costs and Risks (BOCR)-Balance Scorecard Model (BSC)-Analytic Network Process (ANP) was proposed by Shiue and Lin

[26] for the assessment of optimal recycling strategy for renewable energy generation in Turkey. The study considers various costs, risks and environmental factors. The selection of sustainable renewable energy sources in Lithuania is studied by Streimikiene et al. [27] using TOPSIS and Multi-Objective Optimization by Ratio Analysis plus the full multiplicative form (MULTIMOORA) based on the economic dimension, environmental dimension and social dimension. Balezentiene et al. [28] applied FMULTIMOORA for assessing the sustainable energy in Lithuania considering soil carbon sequestration, photosynthesis type, water adaptation, erosion control, input requirement and energy yield. Ertay et al. [29] proposed Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) and FAHP for identifying the accessibility of renewable energy development in Turkey based on risk and feasibility, reliability, social acceptance, labor impact, availability of funds and economic value. The selection of a suitable sustainable energy system in the United Kingdom is studied by Kurka and Blackwood [30] using AHP along with Delta Approximation (DELTAP) and PROMITHEE II. Their study utilizes uncertainty, user-friendliness, flexibility, transparency, communication and multi-stakeholder as an evaluating parameter. Yazdani-Chamzini et al. [31] utilized Complex Proportional Assessment (COPRAS) and AHP for the selection of renewable energy in Iran based on power, investment ratio, implementation period, operating hours, useful life, operation & maintenance cost and CO2 emission. Kabak and Dağdeviren [32] applied ANP to ranking of renewable energy sources in Turkey considering technology, economy, security, global effect and human wellbeing. The ranking of sustainable energy in the USA was investigated by TOPSIS method by Kucukvar et al. [33] based on environmental and socio-economic criteria and their sub-factors. Troldborg et al. [34] used PROMITHEE method for the selection of optimum renewable energy technology in the UK considering power generation, technology maturity, supplier reliability, land requirement, cost and social acceptance as evaluating criteria. Evaluation of renewable energy sources for Turkey, studied by Kuleli Pak et al. [35] using TOPSIS and ANP based on factors such as: energy use per capita, supply efficiency, dependency on imports, climate change, quality of water, and total area of soil. An integrated AHP-TOPSIS approach is proposed for the ranking of energy sources with potential low-carbon emissions for sustainability in Italy by Ren and Sovacool [36]. Their study considers technological maturity, reliability of the resource, acceptability of resources with regard to the social front, support from government and security of energy as an evaluating criterion. Şengül et al. [37] applied FTOPSIS for raking of renewable energy systems in Turkey based on technical, economic and social factors. Al Garni et al. [38] investigated renewable power generation sources for Saudi Arabia using hybrid AHP method considering technical, socio-political, economic, and environmental criteria. Economic, technical, political, social and environmental aspects are taken into consideration by Büyüközkan and Güleryüz [39] for the selection of most appropriate renewable energy sources in Turkey. Their study utilizes DEMATEL and ANP methods for evaluation purposes. Another study was carried out by Büyüközkan and Güleryüz [40] for the selection of optimum renewable energy sources for Turkey using fuzzy preferences with DEMATEL, ANP, TOPSIS methods. Çolak and Kaya [41] applied AHP based type-2 hesitant F-TOPSIS method in an integrated manner for prioritizing renewable energy alternatives in Turkey based on technical, economic, social, environmental criteria with their sub-factors. The sustainability behavior of renewable energy sources at Algeria is studied by Haddah et al. [42] using combined AHP methodology based on social, environmental, economic, and technical concerns. Entropy-COPRAS with different normalization tools are employed for the selection of green energy sources in India by Bhowmik et al. [43]. Their study considers

power generation, capacity factor, useful life, implementation period, cost factors, and CO2 emission. Lee and Chang [44] applied entropy probability technique for ranking of renewable energy sources in Taiwan based on technical, economic, social, environmental criteria with their sub-factors. SWARA-Additive Ratio Assessment (ARAS) method is employed for evaluation of sustainability indicators for renewable energy systems in Turkey by Ghenai et al. [45] considering technical, economic, social, environmental criteria with their sub-factors. Qazi et al. [46] applied Unified Theory of Acceptance and Use of Technology (UTAUT), Sentiment analysis and Entropy-TOPSIS in an integrated manner for identifying the awareness and intention to accept renewable energy sources in Malaysia based on technical efficiency, technological cost, land/price required, job creation, CO2 emission, public opinion, awareness, social influence, performance expectancy, effort expectancy, behavior intention. Bhowmik et al. [47] proposed an integrated AHP-quality function deployment (QFD) methodology for the selection of renewable energy sources in India based on various environmental, social, economic, and security criteria. Evaluation of renewable energy sources for Turkey is studied by Yürek et al. [48] using integrated Pythagorean fuzzy sets (PFSs) based AHP-TOPSIS method and considered capacity factor, availability ratio, evaluation of natural reserve potential, economic life cycle, Levelized electricity generation cost, avoided emission, impact on ecosystem as an evaluating criterion. Salameh et al. [49] applied CRITIC, Entropy, and TOPSIS method in an integrated manner for optimal selection and management of renewable energy system in Saudi Arabia based on various cost factors, capacity, social impact etc. da Ponte et al. [50] proposed AHP and TOPSIS, combined with fuzzy logic, for evaluation of renewable energy generation share in Brazil based on economic, social, robustness, political and technical criteria. Evaluation of renewable energy resources for power generation is studied by Sarkodie et al. [51] using CRITIC weighting technique based MOORA, COPRAS and TOPSIS methodology and considered various cost factors, capacity factor, resource availability, technology maturity, ease of decentralization, efficiency, land use, job creation, socio-political acceptance and levels of CO2 emission. SWOT-based FTOPSIS method is applied to rank the strategic renewable energy alternatives by Akçaba and Eminer [52] for Northern Cyprus based on solar energy potential, geostrategic position in energy transmission, switching to LNG fuel use, hydrocarbon potential in eastern Mediterranean, interconnected connection in energy transmission, decrease in energy investment costs, increasing awareness of energy efficiency, strong university infrastructure, energy efficiency policies, insufficient installed power, dependency on the use of fuel-oil, renewable energy source, energy management, limited use, energy supply security, geopolitical risks, climate change and environmental obligations, international legal regulations, unprepared entry of electric vehicles into the market. Al-Barakati et al. [53] used an extended interval-valued Pythagorean FWASPAS method for evaluation of renewable energy sources based on technical and economic feasibility, economic risks, pollutant emission, land requirement, need of waste disposal, social and political acceptance, water pollutant, investment costs, security of energy supply, source durability as an evaluating criterion. Assessment of renewable energy sources for Tamil Nadu, India is studied by Krishankumar et al. [54] using multi-hesitant fuzzy linguistic based Choquet integral approach. Their study mainly focused on adaptability, job creation, security, durability, pollution control, land use, total production price.

Apart from the above studies that entail the employability of traditional MCDM tools, some of the researchers have also proposed modern MCDM tools to assess green energy sources. These includes tools such as Stable Preference Ordering Towards Ideal Solution

(SPOTIS) [55], Characteristic Object METhod (COMET) [56], Sequential Interactive Modelling for Urban Systems (SIMUS) [57], Data vARIability Assessment Technique for Order of Preference by Similarity to Ideal Solution (DARIA- TOPSI) [58] etc.

For the selection of optimal green energy sources, this study proposes an extended FTODIM method. According to the existing literature, this study can assert that it is the initial research to apply the proposed methodology in the area of green energy. Fuzzy theory is incorporated into the decision-making process as the assessments of decision-makers regarding criteria and alternatives are typically imprecise [59]. In fuzzy-decision making process, linguistic rapports are casted off to epitomize decision makers' judgements. This is the main reason of adopting fuzzy theory in green energy sources selection. For illustration purpose, it is quite easier to represent the green energy source selection criteria as good, very good, poor, very poor etc. than in numbers. The experts assign linguistic terminology to the green energy selection parameters and alternatives, which are then summed up using Schweizer-Sklar and power averaging operators. These operators deal with swayed judgments from decision-makers, which would otherwise have had a negative impact on the final results. TODIM method ranks the established alternatives when taking into account the decision maker's risk appetite. The option with the highest score rating is the best and is recommended for long-term sustainability, followed by other options. The influence and novelty of the present work can be summarized as:

- To propose a novel decision-support system for the evaluation of green energy sources that gives due consideration to the risk appetite of the experts. Moreover, the proposed approach also takes care of the swayed judgement during the process which otherwise could adversely affect the decision-making process.
- To carry out performance analysis of the green energy sources under the influence of the conflicting factors and hence select the optimum one.
- To check the consistency in the decision-making process using sensitivity analysis.

3. METHODOLOGY

This section delivers an outline of the proposed decision-making framework for the selection of optimal green energy sources. The framework models the linguistic evaluation in terms of interval-valued intuitionistic fuzzy numbers [60, 61]. Fig. 1 depicts the decision-making structure that has been adopted to carry out performance analysis of the considered green energy sources. The proposed framework has several associated advantages:

- It pays due respect to the risk appetite of the decision maker while they evaluate the alternatives.
- It takes care of the biased evaluations which may be provided by the decision maker during their evaluations.
- The decision-making approach provides flexibility to the experts involved in evaluating the alternatives and henceforth in arriving at the final rankingsTo check the consistency in the decision-making process using sensitivity analysis.

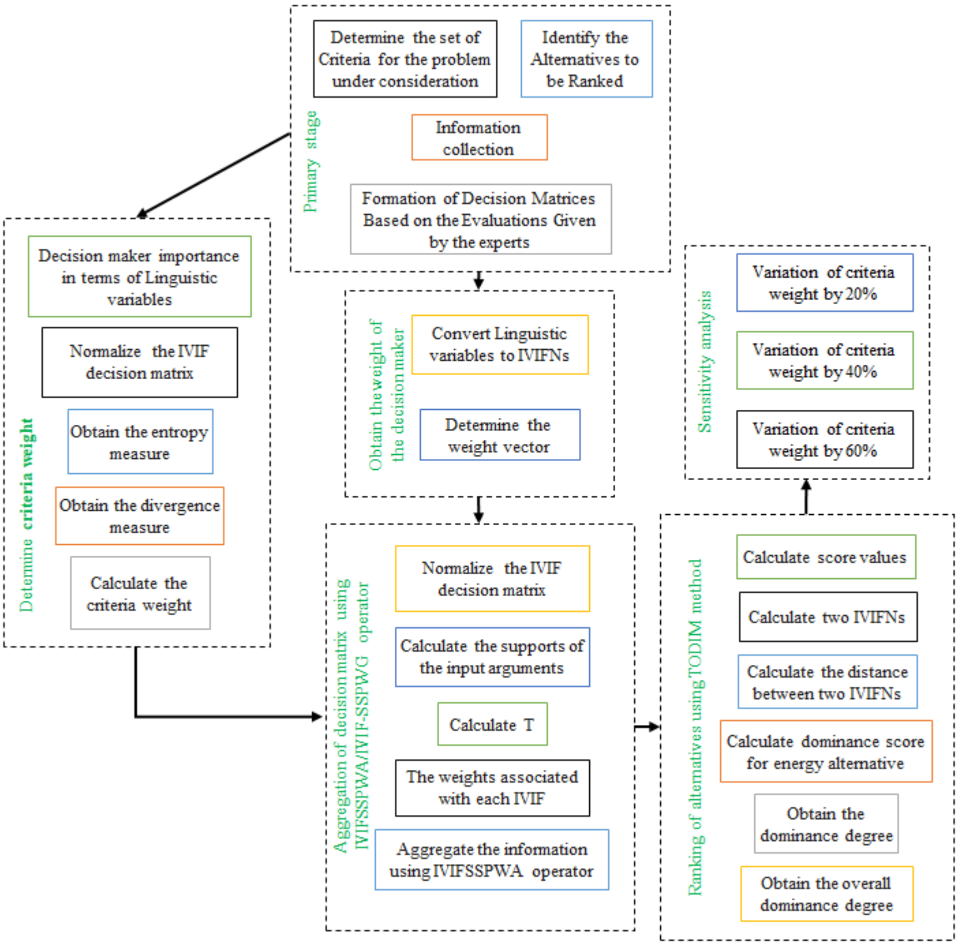

Fig. 1 Proposed framework for green energy selection

The following steps are involved in the proposed extended TODIM approach:

Step 1: The alternatives {A_1, A_2, …, An}to be evaluated as well as the criteria {C_1, C_2, …, Cn} under which evaluations are to be made are identified. Within this stage, the decision makers are also identified to provide their linguistic evaluations. The evaluations are converted into interval-valued intuitionistic fuzzy (IVIF) numbers in accordance with a standard scale. Let the decision matrix be represented as;

$$R^k=(r_{ij}^k)_{m\times n}(k=1,2,...,q),$$

where $r_{ij}^k=([a_{ij}^k,b_{ij}^k],[c_{ij}^k,d_{ij}^k])$ represents interval-valued intuitionistic fuzzy (IVIF) number.

Step 2: The weight associated with the identified experts is evaluated using Eq. (1) as follows:

$$\dddot{w}_k=\frac{[m_q^-+n_q^-\{\frac{m_q^-}{m_q^-+n_q^-}\}]+[m_q^-+n_q^+\{\frac{m_q^+}{m_q^++n_q^+}\}]}{\sum_{k=1}^{q}[\{m_q^-+n_q^-(\frac{m_q^-}{m_q^-+n_q^-})\}+\{m_q^-+n_q^+(\frac{m_q^+}{m_q^++n_q^+})\}]},k=1,2,..., \tag{1}$$

where $e_q=<[m_q^-, m_q^+], [n_q^-, n_q^+]>$ denotes the rating of the q^{th} decision maker in terms of IVIF numbers.

Step 3: Within the scope of this stage of the proposed approach, normalization of the obtained decision matrix is carried out. This process aids in converting the different performance metrics or criteria into similar types. Eqs. (2) and (3) are employed to obtain the normalized values for beneficial and non-beneficial criteria, respectively:

$$r_{ij}=\{(a_{ij}^k,b_{ij}^k),(c_{ij}^k,d_{ij}^k)\} \tag{2}$$

$$r_{ij}=\{(c_{ij}^k,d_{ij}^k),(a_{ij}^k,b_{ij}^k)\} \tag{3}$$

Step 4: In this step, calculations of support values are used in accordance with Eq. (4)

$$Sup(r_{ij}^k,r_{ij}^t)=1-d(r_{ij}^k,r_{ij}^t) \tag{4}$$

where the support from one IVIFN to the other is represented by Sup (r_{ij}^k, r_{ij}^t) and the distance between two IVIFNs by d (r_{ij}^k, r_{ij}^t).

Step 5: Eq. (5) is followed to arrive at the values of $T(r_{ij}^k)$:

$$T(r_{ij}^k)=\sum_{\substack{\&t=1\\ \&t\neq k}}^{p} Sup(r_{ij}^k,r_{ij}^t) \tag{5}$$

where the summation of all the support values is represented by $T(r_{ij}^k)$.

Step 6: The weights (δ_{ij}^k) associated with each IVIF evaluation are calculated using Eq. (6):

$$\delta_{ij}^k=\frac{w_k\{1+T(r_{ij}^k)\}}{\sum_{k=1}^{p} w_k\{1+T(r_{ij}^k)\}} \tag{6}$$

where the weight of an expert is represented by w_k.

Step 7: Obtained evaluations in the form of decision matrices are now aggregated into a single decision matrix. This is accomplished with the aid of Schweizer-Sklar power weighted average (IVIFSSPWA) operator. The detailed formulation for IVIFSSPWA operator can be found in [60].

Step 8: In the present step of the proposed approach, calculations associated with the criteria weights and hence the relative weights of each of the performance metric are approached. The criteria weights can be obtained using any of the weight determination procedures as per the problem under consideration as for instance suggested by [62]. Thus, to uphold the brevity of the piece, the weight determination procedure hasn't been depicted here. With the aid of derived criteria weights, calculation for the relative weights (w_{rc}) associated with the performance metrics is approached using Eq. (7):

$$w_{rc}=\frac{w_{cn}}{w_r} \tag{7}$$

where w_r is the reference weight and w_{cn} is the weight of criteria.

Step 9: At this stage of the proposed approach for appraising the identified alternatives, Eq. (8) is used to calculate the dominance degree for each of the identified alternative over the remaining identified alternatives i.e., δ ($R_i^{\sim}$, $R_j^{\sim}$).

$$\delta(\widetilde{R}_i,\widetilde{R}_j)=\sum_{c=1}^{n}\phi_j(\widetilde{R}_i,\widetilde{R}_j)\forall(i,j) \quad (8)$$

where ϕ_c represents the local dominance score and θ represents attenuation factor.

Step 10: In the last but one step, the calculations for the overall dominance score, $\xi(A_i)$, is processed using Eq. (9).

Step 11: The final rankings of the alternatives are obtained through either of the two approaches:

$$\xi(A_i)=\frac{[\sum_{k=1}^{m}\delta\{\widetilde{R}_i,\widetilde{R}_j\}]-\min_i\{\sum_{k=1}^{m}\delta(\widetilde{R}_i,\widetilde{R}_j)}{\max_i\sum_{k=1}^{m}\delta\{\widetilde{R}_i,\widetilde{R}_j\}]-\min_i\{\sum_{k=1}^{m}\delta(\widetilde{R}_i,\widetilde{R}_j)} \quad (9)$$

(1) γ levels form the basis of ranking the green energy alternatives. Therefore, in this approach, the decision maker is provided with the flexibility to make the final decision in accordance with the different γ levels.

(2) In the second approach, the final rankings for the identified alternatives are obtained by the decision-maker through the calculations for the average overall dominance degree which can be obtained by pursuing a comprehensive evaluation approach. Eq. (10) depicts the formulation for the average overall dominance degree. This approach is useful when the decision maker doesn't have understanding on the γ levels.

$$\overline{\{\xi(A_i)\}}=\frac{1}{F}\sum_{f=1}^{F}\xi_f(A_i) \quad (10)$$

4. Illustrative Example

This section describes the application of the proposed fuzzy TODIM approach to evaluate the effectiveness of existing green energy sources in each region to improve its sustainability problem. In the primary stage i.e., in *step 1* of the decision-making process, criteria {C_1, C_2, …, C_n}and the alternatives {A_1, A_2, …, A_n} are deciphered from various literature and a decision matrix is formed. In the present case, following twelve alternatives have been evaluated: solid waste (A_1), solar (A_2), tidal (A_3), carbon capture and storage (A_4), hydrogen (A_5), marine (A_6), hydel (A_7), biogas (A_8), wind (A_9), concentrating solar (A_{10}), geothermal (A_{11}), and biomass (A_{12}). A brief description of the considered alternatives is as below.

Solid waste: Solid waste can be used as a source of energy through a process known as waste-to-energy (WTE) [63]. WTE involves converting solid waste into electricity or heat through various technologies, such as incineration, gasification, and pyrolysis [64]. *Solar:* Solar energy is a renewable and sustainable source of energy that is generated from the sun's rays. It is considered one of the cleanest and most abundant energy sources available on Earth, as it does not produce any harmful emissions or pollutants during its generation or use. There are two main ways to harness solar energy: solar photovoltaics (PV) and solar thermal systems. Solar PV systems use solar panels to convert sunlight directly into electricity, while solar thermal systems use sunlight to heat a fluid, which then generates electricity through a turbine or other means. Solar energy has several advantages over traditional sources of energy, such as coal and natural gas. It is a clean and renewable energy source, which means it does not contribute to climate change or air pollution. Solar energy systems also require very little maintenance, and once installed, they can generate electricity for decades. Additionally, solar energy can provide energy independence for households and businesses, as they can generate their own electricity and reduce their dependence on the grid [65].

Tidal: Tidal energy is a form of renewable energy that is generated from the movement of ocean tides. Tidal energy is harnessed using tidal turbines that are installed underwater in areas of high tidal movement, such as bays, estuaries, and channels. These turbines work by capturing the kinetic energy of the moving water and converting it into electricity, much like a wind turbine. Tidal energy has several advantages over other forms of renewable energy. Tidal currents are predictable and consistent, which means that tidal energy can be generated continuously without the need for large energy storage systems [66].

Carbon capture and storage: Carbon Capture and Storage is a technology that is used to capture carbon dioxide (CO_2) emissions from industrial processes and store them underground or in other secure locations, such as depleted oil and gas or deep saline aquifers. It involves three main steps: capture, transportation, and storage. In the capture stage, CO_2 is separated from other gases emitted from industrial processes, such as power plants, cement factories, and steel mills. In the transportation stage, the captured CO_2 is transported via pipelines or other means to the storage location. Finally, in the storage stage, the CO_2 is injected into deep geological formations where it can be securely stored for long periods of time. It has the potential to significantly reduce greenhouse gas emissions from industrial processes, and it can be used to mitigate the impact of climate change [67]. However, technology is still in the early stages of development and deployment, and there are several challenges that need to be addressed. These include the high cost, the energy required to capture and transport CO_2, and the need for regulatory frameworks to ensure the safe and secure storage of CO_2.

Hydrogen: Hydrogen is the most abundant element in the universe and can be obtained from a variety of sources, such as water, natural gas, and biomass. Hydrogen can be used as a fuel for vehicles, power generation, heating, and other applications. One of the main advantages of hydrogen energy is that it produces no greenhouse gas emissions when used as a fuel. When hydrogen is burned, the only by-product is water vapor. This makes hydrogen a potentially important source of clean energy that could help reduce our dependence on fossil fuels and mitigate climate change [68]. There are also some challenges associated with hydrogen energy. One of the main challenges is the cost of producing, storing, and transporting hydrogen. Currently, most hydrogen is produced from natural gas through a process called steam methane reforming, which is energy-intensive and produces carbon dioxide emissions. Developing more cost-effective and sustainable methods of producing hydrogen will be essential for its widespread adoption as a source of energy. Another challenge is the development of hydrogen infrastructure, including production facilities, storage facilities, and distribution networks. While hydrogen can be transported by pipelines or tanker trucks, these systems are not yet widely available or cost-effective.

Marine: Marine energy refers to the energy that can be derived from the ocean's waves, currents, and thermal gradients. Marine energy is a renewable and sustainable source of energy that has the potential to reduce our dependence on fossil fuels and mitigate climate change. There are several types of marine energy technologies, including wave energy converters, tidal energy turbines, ocean current turbines, and ocean thermal energy conversion systems [69]. One of the advantages of marine energy is that it is predictable and consistent. Unlike wind and solar energy, which can be intermittent and variable, ocean energy resources are more reliable and can be forecasted with a high degree of accuracy.

Additionally, marine energy has the potential to provide electricity to coastal communities that are not connected to a power grid or to supplement the energy needs of existing coastal infrastructure.

Hydel: Hydel energy, also known as hydroelectric power, is a renewable energy source that is generated by the movement of water. Hydel energy is produced by harnessing the energy of falling water to turn turbines, which generate electricity. The process of generating hydel energy starts with the water being collected in a reservoir. When the water is released through the reservoir, it flows through a large pipe that leads to a turbine. The force of the water turns the turbine, which in turn drives a generator to produce electricity. Hydel power plants typically use dams to store water in reservoirs, which creates a height difference or head. This head of water is then released through turbines, which turn generators to produce electricity. The amount of energy that can be produced by a hydel power plant depends on the volume of water flow and the height of the head. Hydel energy is a renewable and sustainable source of energy, as water is constantly replenished through the water cycle. It also produces no greenhouse gas emissions and has a relatively low operating cost once the dam and hydropower plant are built [70].

Biogas: Biogas energy refers to the production of energy through the conversion of organic matter, such as agricultural waste, or municipal waste. Biogas is primarily composed of methane and CO_2 and can be used as a fuel for electricity generation or as a replacement for fossil fuels in heating and transportation. It is produced by the breakdown of organic matter in the absence of oxygen, a process known as anaerobic digestion. The process of generating biogas energy starts with the collection and transportation of organic waste to a biogas plant. The waste is then mixed with water and placed in a sealed container called a digester, where microorganisms break down the organic matter and produce biogas. The biogas is then purified to remove impurities such as carbon dioxide and hydrogen sulfide before being used as fuel. However, there are also some challenges associated with biogas energy. The production of biogas can be expensive and requires significant infrastructure, such as biogas plants and transportation systems. In addition, the quality and quantity of biogas can be affected by factors such as the type of organic waste and the efficiency of the digester [71, 72].

Wind: Wind power is the process of producing electricity by using wind turbines to transform wind energy into usable forms of energy [73].

Concentrating Solar: Concentrating solar power (CSP) is a technology that generates electricity by focusing the sun's energy onto a small area to create heat [74]. This heat is then used to generate steam, which drives a turbine and produces electricity. CSP systems use mirrors or lenses to concentrate the sunlight onto a receiver, which is typically located at the top of a tower. However, some challenges are associated with CSP, such as the high cost of building and maintaining CSP systems. In addition, CSP systems require a large amount of land, which can have environmental impacts.

Geothermal: Geothermal energy is the energy derived from the natural heat of the Earth's interior. The Earth's interior is extremely hot, with temperatures reaching up to 6,000 degrees Celsius at the core. This heat can be harnessed and converted into electricity using geothermal power plants [75].

Biomass: It describes any living or dead biological substance that can be burned as fuel. Biomass energy refers to the energy that is derived from organic matter, such as wood, crops, agricultural waste, and other plant and animal materials. One common method of generating biomass energy is through the combustion of biomass materials. Biomass materials are burned to produce heat, which is then used to produce steam that drives a turbine to generate electricity. The process is like that used in a coal-fired power plant but with the use of renewable organic materials instead of fossil fuels [76].

Table 1 Importance weights as linguistic terms [77, 78]

Linguistic variable	IVIF number
Very important (VI)	[0.80, 0.95], [0.0, 0.05]
Important (I)	[0.65, 0.75], [0.15, 0.20]
Modest (M)	[0.45, 0.55], [0.30, 0.45]
Unimportant (U)	[0.20, 0.30], [0.55, 0.70]
Very unimportant (VU)	[0.00, 0.10], [0.80, 0.90]

Table 2 Ratings of alternatives using linguistic values [79]

Linguistic variable	IVIF number
Very very poor (VVP)/ very very low (EEL)	[0.00, 0.10], [0.85, 0.90]
Very poor (VP)/ very low (EL)	[0.10, 0.15], [0.70, 0.75]
Fairly poor (FP)/ moderate low (OL)	[0.30, 0.40], [0.45, 0.50]
Poor (P)/ low (L)	[0.15, 0.25], [0.55, 0.60]
Fair (F)/ moderate (O)	[0.40, 0.50], [0.35, 0.40]
Fairly good (FG)/ moderate high (OH)	[0.50, 0.60], [0.25, 0.30]
Good (G)/ high (H)	[0.60, 0.70], [0.20, 0.25]
Very good (VG)/ very high (EH)	[0.70, 0.80], [0.15, 0.20]
Very very good (VVG)/ very very high (EEH)	[0.80, 0.90], [0.05, 0.10]
Extremely good (XG)/ extremely high (XH))	[0.90, 0.95], [0.0, 0.05]

The evaluations have been carried out under the influence of following nine criteria: annual generation (C_1), capacity factor (C_2), mitigation potential (C_3), useful life (C_4), installation period (C_5), energy requirement (C_6), CO_2 emission (C_7), generating cost (C_8) and operations and maintenance cost(C_9). A group of three experts is subsequently selected to provide their linguistic evaluations. Three experts were selected and represented as $\{D_1, D_2, \ldots, D_n\}$. One of the experts belonged to the domain of energy engineering and technology and had vast experience of renewable energy technologies, energy storage solutions etc. The second expert had enormous experience in the domain of energy management and planning. The third expert was an environmentalist and had rich experience in environmental science and sustainability

Those experts were asked to provide the importance of criteria in terms of linguistic information. After this, converted to IVIF numbers using the scale represented in Table 1. The designated decision makers are also asked to appraise the alternatives with admiration to the considered criteria. Thereafter, the evaluations are provided in terms of linguistic information and converted to IVIF numbers using the scale depicted in Table 2. Table 3, Table 4 and Table 5 depict the provided evaluations respectively.

Table 3 Decision matrix by decision maker 1

Dec. maker	*D1*											
Green energy alternative	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}
C_1	P	P	G	P	G	P	G	VG	G	F	G	P
C_2	G	G	F	P	F	G	F	G	P	P	G	P
C_3	P	F	F	P	G	F	F	VG	G	G	VG	F
C_4	G	F	F	G	F	F	F	VG	G	F	VG	F
C_5	VP	P	P	P	F	F	F	VG	G	G	F	G
C_6	P	P	P	F	F	F	F	G	F	F	P	F
C_7	VP	P	P	VG	VG	G	G	VG	VG	VG	VG	G
C_8	VP	P	P	F	G	F	F	VG	G	F	G	F
C_9	VP	P	VP	P	F	P	P	F	F	F	G	F

Table 4 Decision matrix by decision maker 2

Dec. maker	D_2											
Green energy alternative	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}
C_1	P	G	P	P	F	F	F	G	P	P	G	P
C_2	G	VG	F	P	F	F	F	G	P	P	F	P
C_3	P	F	F	P	G	F	G	VG	G	G	VG	F
C_4	P	F	F	G	F	G	F	VG	F	F	VG	F
C_5	VP	P	P	P	F	P	F	VG	G	G	F	G
C_6	P	P	P	F	F	F	P	G	F	F	P	F
C_7	P	P	P	VG	VG	G	G	VG	VG	VG	VG	G
C_8	VP	P	P	F	G	F	F	VG	G	F	G	F
C_9	VG	P	VP	P	F	P	P	F	F	F	G	P

In *step 2* of the approach that has been devised for evaluating the identified green energy sources, Eq. (1) is applied to arrive at the weights for each of the designated experts. Following weight vector was established through the formulation:

$w = (0.394, 0.274, 0.332)^T$

Table 5 Decision matrix by decision maker 3

Dec. maker	D_3											
Green energy alternative	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}
C_1	G	P	G	P	F	F	F	G	P	P	G	P
C_2	G	VG	F	F	F	F	F	G	P	P	F	P
C_3	P	F	G	P	G	F	G	VG	G	G	VG	G
C_4	P	F	F	G	F	G	F	VG	F	F	VG	F
C_5	VP	P	P	P	F	P	F	VG	G	G	F	G
C_6	P	P	P	F	F	F	P	G	F	F	P	F
C_7	P	VP	P	VG	VG	G	G	VG	VG	VG	VG	G
C_8	P	P	P	F	G	F	F	VG	G	F	G	F
C_9	G	VP	VP	VP	F	P	P	F	F	P	G	P

In *step 3*, the decision matrices provided by the three experts are normalized through Eqs. (2-3). In the present case, annual generation, capacity factor, mitigation potential and useful life are the beneficial criteria. On the other hand, installation period, energy requirement, CO_2 emission, generating cost and operations and maintenance cost are the non-beneficial criteria.

In *step 4*, the supports for each of the evaluations are obtained employing Eq. (4).

In *step 5*, the values associated with $T(r_{ij}^k)$ are obtained using Eq. (5).

In *step 6*, the calculations for the weights (δ_{ij}^k) associated with each of the evaluations are determined using Eq. (6).

In the following step *(step 7)*, the decision matrices are aggregated using the equation as given in [59]. The obtained aggregated decision matrix for one alternative has been shown in Table 6 due to space limitations. Now the relative weights of the performance metrics that have been considered to evaluate the alternatives are calculated using Eq. (7). The values derived for the weights have been presented in Table 7.

Table 6 Aggregated decision matrix obtained using Schweizer–Sklar fuzzy TODIM method for one alternative

Green energy	A_1
C_1	(0.3, 0.4, 0.506, 0.5)
C_2	(0.64, 0.743, 0.369, 0.766)
C_3	(0.3, 0.4, 0.506, 0.5)
C_4	(0.61, 0.715, 0.362, 0.745)
C_5	(0.15, 0.25, 0.485, 0.4)
C_6	(0.3, 0.4, 0.506, 0.5)
C_7	(0.15, 0.25, 0.485, 0.4)
C_8	(0.15, 0.25, 0.485, 0.4)
C_9	(0.15, 0.25, 0.485, 0.4)

In *step 9*, Eq. (8) is employed to obtain the results for the dominance degree of each alternative under consideration over the other remaining identified alternatives. The values derived for the dominance degree have been shown in Table 7.

In *step 10*, calculations of overall dominance degree are followed. This is accomplished using Eq. (9).

In *step 11*, both or either of the following methodologies can be employed to deduce the final ranking results:

(1) As per the first approach, the decision-maker considers the value of γ for ranking of the alternatives. Therefore, this very approach allows flexibility to the decision-makers as they have the leverage to opt for the ranking results as per their choice of γ values. Table 8 depicts the values associated with the overall dominance score at different γ values for the considered alternatives.

Table 7 Weights and relative weights of the different criteria

Criteria	w_{cn}	w_{cr}
C_1	0.1104	0.6671
C_2	0.1024	0.6182
C_3	0.0939	0.5640
C_4	0.0817	0.4937
C_5	0.1366	0.8252
C_6	0.0874	0.5282
C_7	0.1096	0.6622
C_8	0.1128	0.6815
C_9	0.1656	1.0000

Table 8 Overall dominance score $\{\overline{\xi(A_i)}\}$ of alternatives at different γ and θ values

Average overall dominance degree	Green energy	Gamma level 0	-1	-2	-5	-20	-50	-200
θ = 1	A_1	0.9440	0.9640	0.9663	0.9783	0.9796	0.9876	0.9888
	A_2	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	A_3	0.9558	0.9748	0.9780	0.9930	0.9951	0.9966	0.9979
	A_4	0.1343	0.1573	0.1592	0.1752	0.1775	0.1793	0.1804
	A_5	0.2849	0.3139	0.3170	0.3280	0.3299	0.3315	0.3329
	A_6	0.2943	0.3163	0.3187	0.3367	0.3388	0.3400	0.3415
	A_7	0.5115	0.5325	0.5348	0.5558	0.5575	0.5586	0.5603
	A_8	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	A_9	0.0326	0.0556	0.0577	0.0697	0.0716	0.0733	0.0745
	A_{10}	0.2523	0.2703	0.2720	0.2850	0.2871	0.2883	0.2897
	A_{11}	0.3460	0.3680	0.3708	0.3888	0.3914	0.3935	0.3947
	A_{12}	0.2125	0.2365	0.2387	0.2577	0.2600	0.2618	0.2637

(2) In this approach, the raking results are derived using the values of the average overall dominance degree $\{\bar{\xi}(A_i)\}$ i.e., the values obtained using Eq. (10). The approach is more useful in case the expert doesn't have any understanding of the γ values. Therefore, the experts can arrive at the best alternative solution through an inclusive performance instead of making the final decision based on different γ value. The results have been tabulated in Table 9.

Table 9 Average overall dominance degree of alternatives and their ranking results

Green energy	Average overall dominance score	Rank
A_1	0.9727	3
A_2	1.0000	1
A_3	0.9844	2
A_4	0.1662	10
A_5	0.3198	7
A_6	0.3266	6
A_7	0.5444	4
A_8	0.0000	12
A_9	0.0621	11
A_{10}	0.2778	8
A_{11}	0.3790	5
A_{12}	0.2473	9

5. Sensitivity Analysis

Sensitivity analysis in decision-making is a technique used to determine how different variables or parameters influence the outcome of a decision model. Several methods can be used to conduct sensitivity analysis, including the adjustment of criteria weights, proportional variation of weights, and other techniques [80]. The stability of the ranking results is validated in this paper through an analysis of changes in criteria weights. This is achieved by systematically adjusting the weights by 20%, 40%, and 60%, one at a time. The obtained results for the performance appraisal based on the first approach of the proposed methodology have been presented in Figs. 2, 3 and 4, respectively. This has been accomplished for θ = 1. The stability of ranking results with respect to varying criteria weights is also illustrated in Fig. 5. Impact analysis of the changing values of attenuation factor onto the ranking results has also been carried out. Different values of attenuation factor i.e., 0.1, 2, 5 and 10 have been considered. The impact of varying attenuation factor values on the ranking results has also been analyzed. Attenuation factors of 0.1, 2, 5, and 10 have been considered. The results are shown in Fig. 3. While the ranking is noticeably affected at higher attenuation factor values, the overall ranking results remain stable. The analysis provides flexibility to the decision-maker or the policy maker regarding the choice of optimal green energy source. In case the selected optimal green energy source becomes unavailable then the decision maker can adopt other sources of energy with due consideration to the different constraints such as climatic conditions, geographical location etc. In the present study, the outlook of the decision maker has been considered as the key variable entity for the considered criteria weight. The prevailing models on optimal green energy source selection lay emphasis only on one criteria weight while the present study considers a variety of local factors and is therefore inclusive over the prevalent models. The presented study is therefore novel in the domain of green energy source selection for the Indian state of Tripura. Hence, the presented work can be employed by policymakers, decision-makers and energy managers as a benchmark for enhancing reliability in planning towards sustainable development goals.

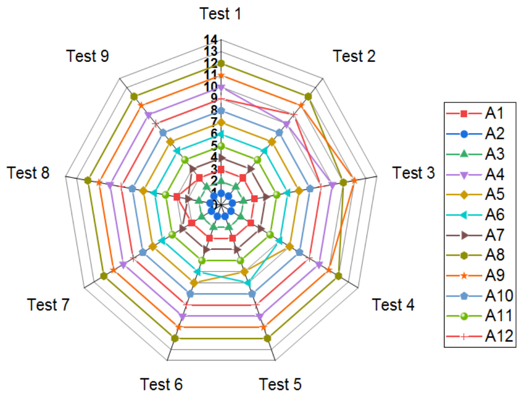

Fig. 2 Variation of criteria weight by 20%

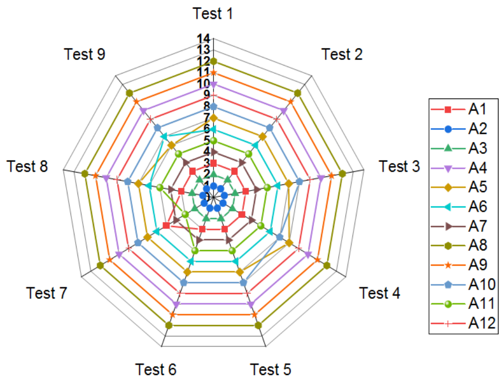

Fig. 3 Variation of criteria weight by 40%

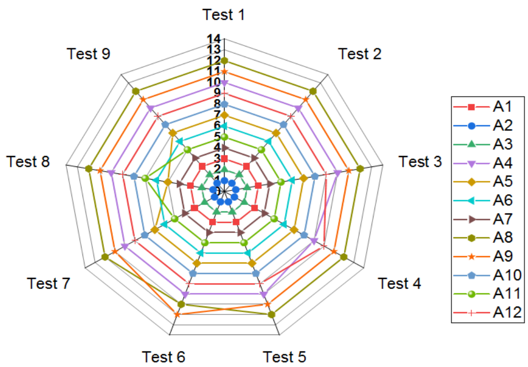

Fig. 4 Variation of criteria weight by 60%

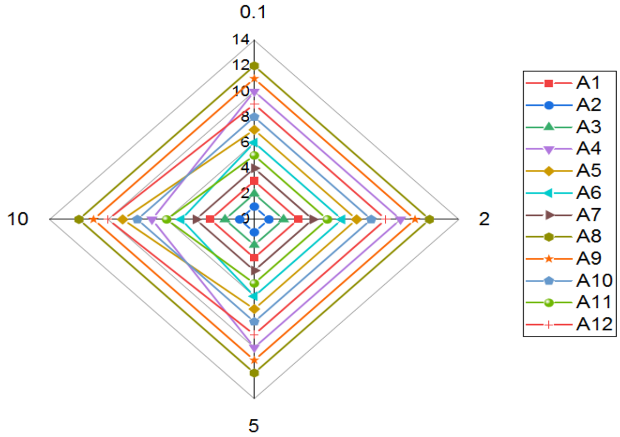

Fig. 5 Variation of attenuation factor and its impact on ranking results

6. CONCLUSIONS

Green energy within a diverse and mixed energy environment is seen as both a challenge and an opportunity. Researchers from various sectors are actively engaged globally in this pursuit, with the aim of generating valuable and practical outcomes. In this complex scenario, uncertainties are managed, and various factors are addressed to achieve optimal energy solutions. As the energy sector evolves, the integration of green energy sources, alongside balancing traditional and renewable alternatives, is considered crucial for advancing sustainability and meeting global energy demands. A pragmatic perspective has been offered in this paper for energy managers, stakeholders, investors, and other key decision-makers, to guide them in making informed choices and analyzing the impact of multiple criteria in green energy selection process. A decision-making framework based on the interval-valued intuitionistic fuzzy TODIM method is introduced to evaluate various green energy alternatives. These alternatives are rigorously evaluated using both quantitative and qualitative performance indicators, providing a comprehensive analysis of their potential. The analyzed energy alternatives and their operational properties are selected based on a comprehensive literature review. Qualitative and quantitative data analyses are performed to identify the optimal green energy alternative. In this study, the proposed decision-making framework integrates prospect theory approach with Schweizer-Sklar and power-averaging operators to evaluate the energy sources effectively. The vagueness of information associated with all the biasing evaluations is taken care of by the Schweizer-Sklar and power averaging operators wherein the TODIM approach takes into consideration the risk appetite of the decision maker while they provide their evaluations. The results obtained through the adopted methodology corroborate with the findings established in the real world-application of the work carried out by earlier researchers. The key conclusions are:

- In accordance with the results obtained from the presented work, solar photovoltaic is the best ranked energy source which is then followed with the rest sources of energy. In case the energy from solar photovoltaic gets exhausted, then other sources of energy since their rankings can be adopted for the generation purpose.

- Out of the considered criteria, the criteria on maintenance cost are weighted the most and, one of the influential factors in opting for the best solution. On the other hand, useful life as one of the criteria has the least impact on the decision-making process as is evident from the derived criteria weights.
- The selected green energy source is optimum in terms of annual generation, capacity factor, mitigation potential, useful life, installation period, energy requirement, CO_2 emission, generating cost and operations and maintenance cost.
- The evaluating factors considered in this study ensure sustainable green energy planning for the selected region.
- The judgements made by this proposed model ensure that the selected green energy can consistently fulfil the energy demand of the area under consideration.

The proposed model shows its application in the conflicting environment of the selected study. The results obtained are based on the performance metrics that have been identified through the exhaustive literature review. There are obvious limitations of the presented work. It is the maturity of the involved experts that has an overbearing effect on the accuracy of the obtained results. Incorporating perilous criteria with due regard to assuring decarbonization of the economy in the selection phase may be a potential scope of the presented work. As a future direction to the presented work, the proposed framework can also be employed to other domains of decision-making problems such as selection of suitable site for municipal waste dumping, selection of suitable site for installing charging station, assessment of block chain technologies etc. Moreover, instead of considering Euclidean distances while deriving the ranks, angular distances such as sine, cosine can also be incorporated with the proposed approach. The authors conclude that continuing this study will provide the world with a greater understanding of energy sustainability.

REFERENCES

1. Stojčić, M., Stjepanović A., Stjepanović, Đ., 2019, *ANFIS model for the prediction of generated electricity of photovoltaic modules*, Decision Making: Applications in Management and Engineering, 2(1), pp. 35-48.
2. Ghenai, C., Albawab, M., Bettayeb, M., 2020, *Sustainability indicators for renewable energy systems using multi-criteria decision-making model and extended SWARA/ARAS hybrid method*, Renewable Energy, 146, pp. 580-597.
3. Worighi, I., Maach, A., Hafid, A., Hegazy, O., Van Mierlo, J., 2019, *Integrating renewable energy in smart grid system: Architecture, virtualization and analysis*, Sustainable Energy, Grids and Networks, 18, 100226.
4. Kizielewicz, B., Sałabun, W., 2024, *SITW method: A new approach to re-identifying multi-criteria weights in complex decision analysis*, Spectrum of Mechanical Engineering and Operational Research, 1(1), pp. 215-226.
5. Deveci, M., Erdogan, N., Pamucar, D., Kucuksari, S., Cali, U., 2023, *A rough Dombi Bonferroni based approach for public charging station type selection*, Applied Energy, 345, 121258.
6. Gökmener, S., Oğuz, E., Deveci, M., & Göllü, K., 2023, *Site selection for floating photovoltaic system on dam reservoirs using sine trigonometric decision-making model*, Ocean Engineering, 281, 114820.
7. Deveci, M., 2023, Effective use of artificial intelligence in healthcare supply chain resilience using fuzzy decision-making model, Soft Computing, https://doi.org/10.1007/s00500-023-08906-2
8. Ghailani, H., Zaidan, A. A., Qahtan, S., Alsattar, H. A., Al-Emran, M., Deveci, M., Delen, D., 2023, *Developing sustainable management strategies in construction and demolition wastes using a q-rung orthopair probabilistic hesitant fuzzy set-based decision modelling approach*, Applied Soft Computing, 110606.
9. Haralambopoulos, D.A., Polatidis, H., 2003, *Renewable energy projects: structuring a multi-criteria group decision-making framework*, Renewable Energy, 28(6), pp. 961-973.
10. Nigim, K., Munier, N., Green, J., 2004, *Pre-feasibility MCDM tools to aid communities in prioritizing local viable renewable energy sources*, Renewable Energy, 29(11), pp. 1775-1791.
11. Pohekar, S.D., Ramachandran, M., 2004, *Multi-criteria evaluation of cooking energy alternatives for promoting parabolic solar cooker in India*, Renewable Energy, 29(9), pp. 1449-1460.

12. Patlitzianas, K.D., Ntotas, K., Doukas, H., Psarras, J., 2007, *Assessing the renewable energy producers' environment in EU accession member states*, Energy Conversion and Management, 48(3), pp. 890-897.
13. Buchholz, T., Rametsteiner, E., Volk, T.A., Luzadis, V.A., 2009, *Multi criteria analysis for bioenergy systems assessments*, Energy Policy, 37(2), pp. 484-495.
14. Cavallaro, F., 2009, *Multi-criteria decision aid to assess concentrated solar thermal technologies*, Renewable Energy, 34(7), pp. 1678-1685.
15. Chung, E.S., Lee, K.S., 2009, *Prioritization of water management for sustainability using hydrologic simulation model and multicriteria decision making techniques*, Journal of Environmental Management, 90(3), pp. 1502-1511.
16. Doukas, H., Psarras, J., 2009, *A linguistic decision support model towards the promotion of renewable energy*, Energy Sources, Part B, 4(2), pp. 166-178.
17. Kahraman, C., Cebi, S., Kaya, I., 2010, *Selection among renewable energy alternatives using fuzzy axiomatic design: The case of Turkey*, Journal of Universal Computer Science, 16(1), pp. 82-102.
18. Ren, H., Gao, W., Zhou, W., Nakagami, K.I., 2009, *Multi-criteria evaluation for the optimal adoption of distributed residential energy systems in Japan*, Energy Policy, 37(12), pp. 5484-5493.
19. Tsoutsos, T., Drandaki, M., Frantzeskaki, N., Iosifidis, E., Kiosses, I., 2009, *Sustainable energy planning by using multi-criteria analysis application in the island of Crete*, Energy Policy, 37(5), pp. 1587-1600.
20. Heo, E., Kim, J., Boo, K.J., 2010., *Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP*, Renewable and Sustainable Energy Reviews, 14(8), pp. 2214-2220.
21. Kaya, T., Kahraman, C., 2010, *Multicriteria renewable energy planning using an integrated fuzzy VIKOR & AHP methodology: The case of Istanbul*, Energy, 35(6), pp. 2517-2527.
22. Shen, Y.C., Lin, G.T., Li, K.P., Yuan, B.J., 2010, *An assessment of exploiting renewable energy sources with concerns of policy and technology*, Energy Policy, 38(8), pp. 4604-4616.
23. Reza, B., Sadiq, R., Hewage, K., 2011, *Sustainability assessment of flooring systems in the city of Tehran: An AHP-based life cycle analysis*, Construction and Building Materials, 25(4), pp. 2053-2066.
24. San Cristóbal, J.R., 2011, *Multi-criteria decision-making in the selection of a renewable energy project in Spain: The VIKOR method*, Renewable Energy, 36(2), pp. 498-502.
25. Davoudpour, H., Rezaee, S., Ashrafi, M., 2012, *Developing a framework for renewable technology portfolio selection: A case study at a R&D center*, Renewable and Sustainable Energy Reviews, 16(6), pp. 4291-4297.
26. Shiue, Y.C., Lin, C.Y., 2012, *Applying analytic network process to evaluate the optimal recycling strategy in upstream of solar energy industry*, Energy and Buildings, 54, pp. 266-277.
27. Streimikiene, D., Balezentis, T., Krisciukaitienė, I., Balezentis, A., 2012, *Prioritizing sustainable electricity production technologies: MCDM approach*, Renewable and Sustainable Energy Reviews, 16(5), pp. 3302-3311.
28. Balezentiene, L., Streimikiene, D., Balezentis, T., 2013, *Fuzzy decision support methodology for sustainable energy crop selection*, Renewable and Sustainable Energy Reviews, 17, pp. 83-93.
29. Ertay, T., Kahraman, C., Kaya, İ., 2013, *Evaluation of renewable energy alternatives using MACBETH and fuzzy AHP multicriteria methods: the case of Turkey*, Technological and Economic Development of Economy, 19(1), pp. 38-62.
30. Kurka, T., Blackwood, D., 2013, *Selection of MCA methods to support decision making for renewable energy developments*, Renewable and Sustainable Energy Reviews, 27, pp. 225-233.
31. Yazdani-Chamzini, A., Fouladgar, M.M., Zavadskas, E.K., Moini, S.H., 2013, *Selecting the optimal renewable energy using multi criteria decision making*, Journal of Business Economics and Management, 14(5), pp. 957-978.
32. Kabak, M., Dağdeviren, M., 2014, *Prioritization of renewable energy sources for Turkey by using a hybrid MCDM methodology*, Energy Conversion and Management, 79, pp. 25-33.
33. Kucukvar, M., Gumus, S., Egilmez, G., Tatari, O., 2014, *Ranking the sustainability performance of pavements: An intuitionistic fuzzy decision-making method*, Automation in Construction, 40, pp. 33-43.
34. Troldborg, M., Heslop, S., Hough, R.L., 2014, *Assessing the sustainability of renewable energy technologies using multi-criteria analysis: Suitability of approach for national-scale assessments and associated uncertainties*, Renewable and Sustainable Energy Reviews, 39, pp. 1173-1184.
35. Kuleli Pak, B., Albayrak, Y.E., Erensal, Y.C., 2015, *Renewable energy perspective for Turkey using sustainability indicators*, International Journal of Computational Intelligence Systems, 8(1), pp. 187-197.
36. Ren, J., Sovacool, B.K., 2015, *Prioritizing low-carbon energy sources to enhance China's energy security*, Energy Conversion and Management, 92, pp. 129-136.
37. Şengül, Ü., Eren, M., Shiraz, S.E., Gezder, V., Şengül, A.B., 2015, *Fuzzy TOPSIS method for ranking renewable energy supply systems in Turkey*, Renewable Energy, 75, pp. 617-625.
38. Al Garni, H., Kassem, A., Awasthi, A., Komljenovic, D., Al-Haddad, K., 2016, *A multicriteria decision making approach for evaluating renewable power generation sources in Saudi Arabia*, Sustainable Energy Technologies and Assessments, 16, pp. 137-50.

39. Büyüközkan, G., Güleryüz, S., 2016, *An integrated DEMATEL-ANP approach for renewable energy resources selection in Turkey*, International Journal of Production Economics, 182, pp. 435-448.
40. Büyüközkan, G., Güleryüz, S., 2017, *Evaluation of Renewable Energy Resources in Turkey using an integrated MCDM approach with linguistic interval fuzzy preference relations*, Energy, 123, pp. 149-163.
41. Çolak, M., Kaya, İ., 2017, *Prioritization of renewable energy alternatives by using an integrated fuzzy MCDM model: A real case application for Turkey*, Renewable and Sustainable Energy Reviews, 80, pp. 840-853.
42. Haddad, B., Liazid, A., Ferreira, P., 2017, *A multi-criteria approach to rank renewables for the Algerian electricity system*, Renewable Energy, 107, pp. 462-472.
43. Bhowmik, C., Bhowmik, S., Ray, A., 2018, *The effect of normalization tools on green energy sources selection using multi-criteria decision-making approach: A case study in India*, Journal of Renewable and Sustainable Energy, 10(6), 065901.
44. Lee, H., & Chang, C. (2018). *Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan*, Renewable & Sustainable Energy Reviews, 92, pp. 883-896.
45. Ghenai, C., Albawab, M., & Bettayeb, M. (2020). *Sustainability indicators for renewable energy systems using multi-criteria decision-making model and extended SWARA/ARAS hybrid method*, Renewable Energy, 146, pp. 580-597.
46. Qazi, A., Bhowmik, C., Hussain, F., Yang, S., Naseem, U., Adebayo, A.A., Gumaei, A., Al-Rakhami, M., 2021, *Analyzing the Public Opinion as a Guide for Renewable-Energy Status in Malaysia: A Case Study*, IEEE Transactions on Engineering Management, 70(2), pp. 371-385.
47. Bhowmik, C., Bhowmik, S., Ray, A., 2021, *Selection of optimum green energy sources by considering environmental constructs and their technical criteria: a case study*, Environment, Development and Sustainability, 23, pp. 13890-13918.
48. Yürek, Y.T., Bulut, M., Özyörük, B., Özcan, E., 2021, Evaluation of the hybrid renewable energy sources using sustainability index under uncertainty, Sustainable Energy, Grids and Networks, 28, 100527.
49. Salameh, T., Sayed, E.T., Abdelkareem, M.A., Olabi, A.G., Rezk, H., 2021, *Optimal selection and management of hybrid renewable energy System: Neom city as a case study*, Energy Conversion and Management, 244, 114434.
50. da Ponte, G.P., Calili, R.F., Souza, R.C., 2021, *Energy generation in Brazilian isolated systems: Challenges and proposals for increasing the share of renewables based on a multicriteria analysis*, Energy for Sustainable Development, 61, pp. 74-88.
51. Sarkodie, W.O., Ofosu, E.A., Ampimah, B.C., 2022, *Decision optimization techniques for evaluating renewable energy resources for power generation in Ghana: MCDM approach*, Energy Reports, 8, pp. 13504-13513.
52. Akçaba, S., Eminer, F., 2022, *Evaluation of strategic energy alternatives determined for Northern Cyprus with SWOT based MCDM integrated approach*, Energy Reports, 8, pp. 11022-11038.
53. Al-Barakati, A., Mishra, A.R., Mardani, A., Rani, P., 2022, *An extended interval-valued Pythagorean fuzzy WASPAS method based on new similarity measures to evaluate the renewable energy sources*, Applied Soft Computing, 120, 108689.
54. Krishankumar, R., Pamucar, D., Deveci, M., Aggarwal, M., Ravichandran, K.S., 2022, *Assessment of renewable energy sources for smart cities' demand satisfaction using multi-hesitant fuzzy linguistic based choquet integral approach*, Renewable Energy, 189, pp. 1428-1442.
55. Bączkiewicz, A., 2023, *Temporal SWARA-SPOTIS for Multi-Criteria Assessment of European Countries Regarding Sustainable RES Exploitation*, Lecture Notes in Business Information Processing, 471, pp. 171-191.
56. Wątróbski, J., Bączkiewicz, A., Sałabun, W., 2022, *New multi-criteria method for evaluation of sustainable RES management*, Applied Energy, 324, 119695.
57. Quteishat, A., Younis, M.A.A., 2023, *Strategic Renewable Energy Resource Selection Using a Fuzzy Decision-Making Method*, Intelligent Automation & Soft Computing, 35(2), pp. 2117-2134.
58. Bączkiewicz, A., Wątróbski, J., 2022, *Multi-Criteria Temporal Assessment of Afordable and Clean Energy Systems in European Countries Using the DARIA-TOPSIS Method*, Procedia Computer Science, 207, pp. 4442-4453.
59. Petrović, G., Mihajlović, J., Ćojbašić, Z., Madić, M., Marinković, D., 2019, *Comparison of three fuzzy mcdm methods for solving the supplier selection problem*, Facta Universitatis-Series Mechanical Engineering, 17(3), pp. 455-469.
60. Zindani, D., Maity, S.R., Bhowmik, S., 2020, *Interval-valued intuitionistic fuzzy TODIM method based on Schweizer–Sklar power aggregation operators and their applications to group decision making*, Soft Computing, 24, pp. 14091-14133.
61. Zindani, D., Maity, S.R., Bhowmik, S., 2021, *Complex interval-valued intuitionistic fuzzy TODIM approach and its application to group decision making*, Journal of Ambient Intelligence and Humanized Computing, 12(2), pp. 2079-2102.

62. Mishra, A.R., Rani, P., 2018, *Interval-valued intuitionistic fuzzy WASPAS method: application in reservoir flood control management policy*, Group Decision and Negotiation, 27(6), pp. 1047-1078.
63. Hamad, T.A., Agll, A.A., Hamad, Y.M., Sheffield, J.W., 2014, *Solid waste as renewable source of energy: current and future possibility in Libya*, Case Studies in Thermal Engineering, 4, pp. 144-152.
64. Hasan, M.M., Rasul, M.G., Khan, M.M.K., Ashwath, N., Jahirul, M.I., 2021, *Energy recovery from municipal solid waste using pyrolysis technology: A review on current status and developments*, Renewable and Sustainable Energy Reviews, 145, 111073.
65. Siksnelyte-Butkiene, I., Zavadskas, E.K., Streimikiene, D., 2020, *Multi-Criteria Decision-Making (MCDM) for the Assessment of Renewable Energy Technologies in a Household: A Review*, Energies, 13(5), 1164.
66. Chowdhury, M.M.U., Rahman, K.M., Selvanathan, V., Nuthammachot, N., Ramamurthi, K., Mostafaeipour, A., Habib, A., Akhtaruzzaman, Amin, N., Techato, K., 2021, *Current trends and prospects of tidal energy technology*, Environment, Development and Sustainability, 23(6), pp. 8179-8194.
67. Bandilla, K.W., 2020, *Carbon Capture and Storage*, Future Energy (Third Edition), Elsevier, pp. 669-692.
68. Dehshiri, S.J.H., Zanjirchi, S.M., 2022, *Comparative analysis of multicriteria decision-making approaches for evaluation hydrogen projects development from wind energy*, International Journal of Energy Research, 46(10), pp. 13356-13376.
69. Shao, M., Zhang, S., Sun, J., Han, Z., Shao, Z., Yi, C., 2022, *GIS-MCDM-Based Approach to Site Selection of Wave Power Plants for Islands in China*, Energies, 15(11), 4118.
70. Bhowmik, C., Dhar, S., Ray, A., 2019, *Comparative analysis of MCDM methods for the evaluation of optimum green energy sources: A case study*, International Journal of Decision Support System Technology, 11(4), pp. 1-28.
71. Bazmi, A. A., Zahedi, G., 2011, *Sustainable energy systems: Role of optimization modeling techniques in power generation and supply - A review*, Renewable & Sustainable Energy Reviews, 15(8), pp. 3480-3500.
72. Lenzen, M. (2010). *Current state of development of electricity-generating technologies: A literature review*, Energies, 3(3), pp. 462-591.
73. Eroğlu, Ö., Aktaş Potur, E., Kabak, M., Gencer, C., 2023, *A literature review: Wind energy within the scope of MCDM methods*, Gazi University Journal of Science, 36(4), pp. 1578-1599.
74. Rezk, H., Mukhametzyanov, I.Z., Abdelkareem, M.A., Salameh, T., Sayed, E.T., Maghrabie, H.M., Radwan, A., Wilberforce, T., Elsaid, K., Olabi, A.G., 2022, *Multi-criteria decision making for different concentrated solar thermal power technologies*, Sustainable Energy Technologies and Assessments, 52, 102118.
75. Raos, S., Hranić, J., Rajšl, I., Bär, K., 2022, *An extended methodology for multi-criteria decision-making process focused on enhanced geothermal systems*, Energy Conversion and Management, 258, 115253.
76. Bhowmik, C., Kaviani, M.A., Ray, A., Ocampo, L., 2020, *An Integrated Entropy-TOPSIS Methodology for Evaluating Green Energy Sources*, International Journal of Business Analytics, 7(3), pp. 44-70.
77. Mishra, A.R., Rani, P., Mardani, A., Pardasani, K.R., Govindan, K., Alrasheedi, M., 2020, *Healthcare evaluation in hazardous waste recycling using novel interval-valued intuitionistic fuzzy information based on complex proportional assessment method*, Computers & Industrial Engineering, 139, 106140.
78. Bozanic, D., Tešić, D., Marinković, D., Milić, A., 2021, *Modeling of neuro-fuzzy system as a support in decision-making processes*, Reports in Mechanical Engineering, 2(1), pp. 222-234.
79. Bozanic, D., Tešić, D., Komazec, N., Marinković, D., Puška, A., 2023, *Interval fuzzy AHP method in risk assessment*, Reports in Mechanical Engineering, 4(1), pp. 131-140.
80. Biswas, S., Božanić, D., Pamučar, D., Marinković, D. 2023, *A spherıcal fuzzy based decısıon makıng framework wıth eınsteın aggregatıon for comparıng preparedness of SMEs ın Qualıty 4.0*, Facta Universitatis-Series Mechanical Engineering, 21(3), pp. 453-478.