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Original Article

Assessing the Economic Viability of Renewable Energy Subsidies through a Multi-Criteria Decision-Making Framework

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ABSTRACT: *Even though renewable energy subsidies help the transition to more sustainable energy faster, some still argue that they are not economically sensible because of pressing concerns such as budget cuts, market disruptions and their effect on the planet. A Multi-Criteria Decision-Making (MCDM) process is employed in this study to evaluate the effectiveness of renewable energy subsidies, taking into account economic, environmental, technical, and social aspects. Using AHP and CoCoSo, the analysis ranks key factors such as costs, the time required to recover the investment, the project's ability to limit carbon emissions, and potential employment opportunities. Results of case studies in India and Serbia indicate that solar and wind power are most important due to their low cost and ability to be applied on a wide scale. Financial factors like upfront costs and returns mainly decide subsidies, yet the benefits to the environment and society in the long run are a good reason to continue subsidizing such projects. The concept highlights the need to pick technologies that can balance short-term advantages in growth with goals for a better, more sustainable future. Many policy suggestions focus on adjusting who gets subsidies, improving how markets set prices and increasing collaborations with other countries to address trade disagreements. This method for MCDM provides policymakers with a clear tool that relies on data to develop robust renewable plans that both align with global environmental goals and meet local needs.*

KEYWORDS: *Renewable energy subsidies, Economic viability, Multi-criteria decision-making (MCDM), Sustainable energy policy, Cost-benefit analysis, Solar energy, Wind energy, Fiscal policy, Environmental sustainability.*

1. INTRODUCTION

1.1. BACKGROUND AND RATIONALE

Governments around the world are now using renewable energy subsidies to promote the use of green energy and reduce the reliance on fossil fuels. Numerous countries utilize subsidies to promote a more reliable energy supply, reduce pollution, encourage the development of new technologies, and benefit society by helping people find employment and improve their health. Renewable energy subsidies may be in the form of cash payouts, [1-3] reduced taxes, grants, limits on costs or encouragement through laws to help renewable energy be cheaper to produce and use than fossil fuels. These days, support for clean energy has become significantly larger, with renewable sources accounting for a substantial portion of total energy subsidies. Nearly half of federal energy subsidies in the US went to renewables from 2016 to 2022. Even though subsidies are widely used, many debates continue over whether they help and if they are economically sustainable, given the growing costs and changes affecting governments.

1.2. TYPES AND MECHANISMS OF RENEWABLE ENERGY SUBSIDIES

Renewable energy receives financial support through various approaches. Credit schemes and grants, known as Production Tax Credits (PTC) and Investment Tax Credits (ITC), are regular forms of direct incentives in the United States and the United Kingdom. Because these schemes lower the costs for both investors and consumers, renewable resources can compete with fossil fuels. In Europe, feed-in tariffs (FITs), compulsory quota systems, and renewable energy certificates help ensure that those using renewable energy have access to the market and predictable earnings. In addition to direct incentives, features such as rapid depreciation of renewable energy equipment, government assurances on loans, and priority access to the power grid make investing in renewable forms even more appealing. Still, growing numbers of subsidy programs have caused some people to worry about their cost, negative effects on markets, and excessive use, leading countries in recent times to either reduce or reform their support structures.

1.3. CHALLENGES AND THE NEED FOR ECONOMIC ASSESSMENT

Without a doubt, they pushed for a rapid rise in clean energy, leading some to question how it can benefit the economy. Pouring money into subsidies can overburden the budget, causing other useful projects to be cut in poorer nations. One must also consider the potential drawbacks of subsidies, such as increased costs to consumers, additional steps in the regulatory process, and unintended market effects. With the sector opening up and technology becoming more affordable, policymakers are faced with the challenge of implementing subsidies that are effective and accessible. Therefore, the presence of this context emphasizes the need for effective, multi-factor decision-making systems to identify negative consequences and inform policy actions.

2. LITERATURE REVIEW

2.1. RENEWABLE ENERGY SUBSIDIES: GLOBAL TRENDS

The global situation for subsidising renewable energy is undergoing rapid changes due to shifts in policy, technological advancements, and evolving market trends. [4-7] In 2025, the rise in energy generation was mostly because of renewables, which added 38%, more than any other form, such as natural gas, coal, oil or nuclear. Solar Photovoltaic (PV) is driving this expansion, as it is estimated to supply around half of the new electricity needed globally in 2024 and 2025. The increase depends on cheaper technology, improved efficiency and support from the government.

Countries worldwide have dedicated a substantial amount of money to support clean energy. Investments exceeding $2 trillion have been made in clean energy since 2020, underscoring the magnitude and urgency of the energy transition. Significantly, strong growth and leadership are attributed to nations such as the United States, China, India and Australia. Renewable energy in India has grown by an average of 15.4% per year from 2016 to 2023, placing India as the top performer for renewable electricity. The total renewable capacity in India at the end of FY23 was 125.15 GW, expected to double by 2026.

Adaptive policies and trading systems are developed in response to emerging new challenges. International Renewable Energy Certificates (I-RECs) and China's Green Electricity Certificates are introductions designed to track and certify the use of renewable energy. In addition, reforms in permitting and interconnection procedures in Germany, as well as the United States, are clearing up delays and speeding up projects. Still, there are ongoing obstacles. Challenges in certificate markets, the importance of environmentally friendly raw materials for storage development, and risks related to subsidy availability in older markets must continue to be addressed through effective policies. However, things remain positive on a global scale, with renewable power expected to surpass coal in electricity generation by 2025, and energy storage, green hydrogen, and smart grids becoming key areas for targeted support.

2.2. ECONOMIC EVALUATION TECHNIQUES

Evaluating the effectiveness of subsidising renewable energy requires considering all direct and indirect effects. The standard practice of Cost-Benefit Analysis (CBA) measures the economic value gained by comparing the subsidy's costs to the monetary benefits it provides, including reduced emissions, increased jobs, and health improvements. As policymaking on renewable energy becomes more comprehensive, special approaches are being developed that account for the numerous factors involved.

2.3. MCDM METHODS IN ENERGY POLICY

Investors now turn to Life-Cycle Cost Analysis (LCCA) to estimate all the costs involved in a renewable project, such as initial setup, upkeep, and removal of the system at the end of its life. This approach provides a comprehensive view of long-term financial stability, as technology continues to become more accessible and affordable. Examining the payback period and Internal Rate of Return (IRR) is a common approach for determining whether a subsidized project is a good investment choice for investors.

Carbon pricing, avoidance of pollution and boosting social welfare are some of the externalities now incorporated into economic analysis along with financial figures. IAMs and CGE models are both used to project the broader effects of subsidies, which involve GDP, employment rates, and trade flows. They enable policymakers to assess the impact of subsidies on the economy and adjust policies to achieve optimal results. MCDM techniques are popular now because they can easily weigh and combine different criteria such as economic, environmental, technical and social, when analyzing subsidy schemes. MCDM frameworks use both numbers and opinions to create a comprehensive assessment, helping decision-makers consider everything that matters to stakeholders and long-term goals. The progress in economic evaluation of renewable energy highlights the more advanced and wide-reaching goals of clean energy policies everywhere. Evaluating energy policies, particularly subsidies for renewable energy, relies heavily on Multi-Criteria Decision-Making methods. They refer to making decisions in energy systems, where business, environmental, technological, and social considerations must be balanced. When organizing problems by criteria and alternatives, MCDM methods ensure that policy decisions are informed, straightforward and based on facts.

The most common technique in MCDM is the Analytic Hierarchy Process (AHP), which divides complex decisions into comparisons of two features at a time, allowing stakeholders to assign a relative measure to each criterion. In energy policy, this approach is useful since it helps to trade off costs, emissions reduction, reliability, and job creation. Another significant MCDM technique is TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), which ranks possibilities by comparing them to the closest ideal solution. CoCoSo (Combined Compromise Solution) combines different ranking methods to ensure strong decision support.

3. METHODOLOGY

Renewable energy subsidies can be explored and analyzed using the MCDM method, so policymakers can consider grant schemes, feed-in tariffs and tax privileges according to various important factors. This helps ensure that all subsidies are cost-effective and align with sustainability goals. [8-12] MCDM is now used in energy policy to rank new technologies, plan how to allocate funds effectively and measure the effects of changes on society and the economy. MCDM practices are boosted by better tools and platforms for data analysis and stakeholder consultation, which make decisions more accurate and reliable. Since energy production is moving toward decentralization and a mix of different sources, MCDM will play a bigger role in managing renewable energy subsidy plans for maximum gains in the economy, environment and society.

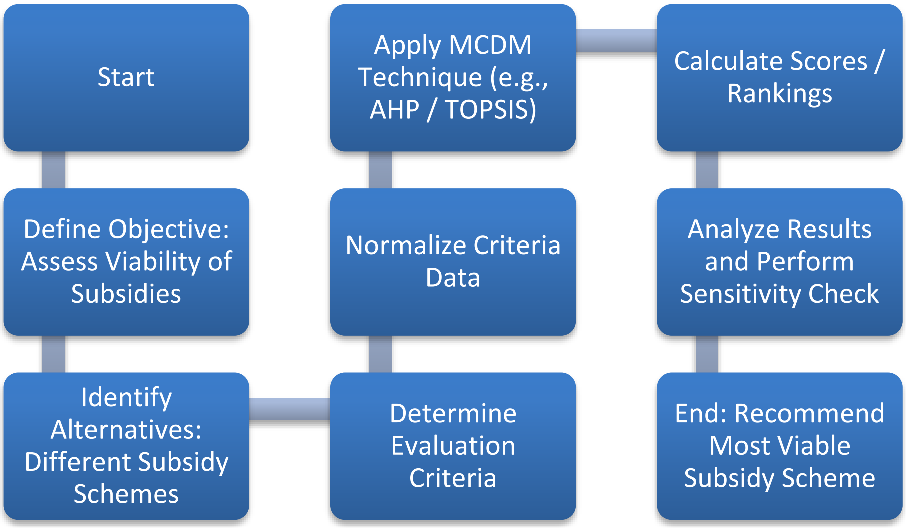

FIGURE 1 MCDM-based evaluation framework

3.1. MULTI-CRITERIA DECISION-MAKING (MCDM) FRAMEWORK

Multi-Criteria Decision-Making (MCDM) is a specialized framework designed to address problems that involve multiple important and often conflicting criteria. In the renewable energy sector, MCDM enables people to systematically evaluate different energy options and subsidy systems by considering economic, environmental, technical, and social aspects. This involves starting by setting the decision goal, for instance, to select the top renewable energy technology for subsidies and then organizes the problem into stages where choices are compared.

Energy policy benefits significantly from MCDM frameworks, as they facilitate more open, repeatable, and evidence-based decision-making. The inclusion of both qualitative and quantitative criteria enables a combination of various stakeholder perspectives and allows for managing flexible trade-offs among different goals. When deciding based on economics, primary issues may include investment and payback period, while environmental criteria, such as greenhouse gas emissions and land use, are vital for sustainability. MCDM approaches have been proven useful in selecting solar Photovoltaic (PV), Concentrated Solar Power (CSP), wind and biomass alternatives by considering various essential criteria that are real-life oriented. The flexibility of MCDM enables it to accommodate various policy environments, areas, and stakeholder priorities, making it useful for selecting subsidy targets and technologies in renewable energy.

3.2. SELECTION OF CRITERIA AND ALTERNATIVES

The way criteria and alternatives are selected is very important because they influence how much of the analysis is covered. Multiple factors are considered in renewable energy policy to illustrate the diverse effects of subsidies, encompassing economic, environmental, technological, and societal aspects. Important criteria often used include investment costs, O&M expenses, energy prices, the space required for building, GHG emissions, water use, technological advancements, energy efficiency, the availability of key resources, and the creation of new jobs. The significance to stakeholders, policy objectives and the context of the decision problem are why these criteria are chosen.

Alternatives include various types of renewable energy and forms of subsidies being explored. In recent research, solar PV, CSP, wind, and biomass are the most common alternatives, and each performs uniquely according to the selected criteria. An example is that solar PV performs well in terms of low cost and high efficiency, but wind energy may provide more resources and create more jobs. Having a range of different alternatives allows the analysis to spot all the options accessible to policymakers. Expert opinions, studies published in reputable sources, and the opinions of stakeholders are often used to help determine criteria and alternatives. The collection, normalization and evaluation of the data all depend on the last set of criteria and alternatives in the MCDM framework.

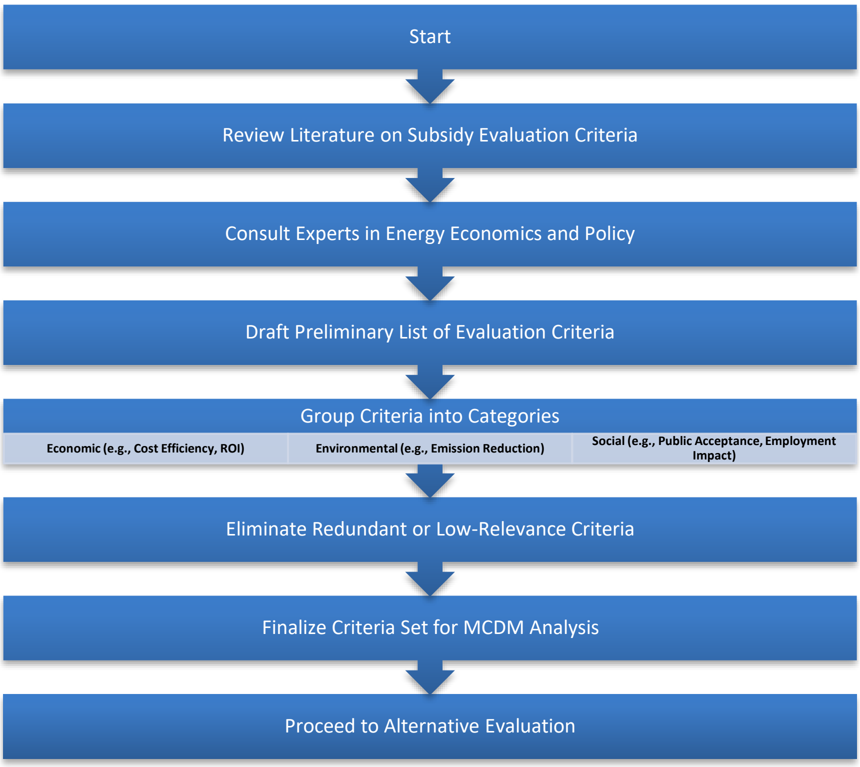

FIGURE 2 Criteria selection process

3.3. DATA COLLECTION AND NORMALIZATION

Reliability and comparisons in the MCDM analysis depend on first gathering and normalizing the data. For each alternative, information is collected using both primary sources (such as expert opinions and stakeholder interviews) and secondary sources (including written literature, technical documents and official statistics). Data must be accurate and consistent, as mistakes can significantly impact the outcome. As the measurements used in the criteria may vary in units and scales, such as costs in USD/kW, emissions in kg CO_2/MWh or efficiency given as a percentage, the data is normalized using standardization. Usually, min-max scaling and z-score standardization are performed to change raw outcomes into scores between 0 (least desirable) and 1 (most desirable). Using this technique helps prevent one measure, which might differ in size or units, from significantly affecting the final decision.

As an illustration, a recent research project applied normalization to factors like investment cost, cost to run/operate, energy cost, land use, greenhouse gas emissions, water use, technical maturity, efficiency, the supply and demand of required resources and job opportunities, which helped ensure a fair comparison of different alternatives. After normalization, the information is read by the MCDM technique, which helps make the process clear and repeatable.

3.4. DESCRIPTION OF MCDM TECHNIQUE USED

Selecting the proper MCDM technique affects both the way the results are analyzed and their interpretation. When analyzing subsidies for renewable energy, Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Combined Compromise Solution (CoCoSo) are often applied as established MCDM methods. All the methods provide different ways to set up, weight and arrange alternatives.

To illustrate, the CoCoSo method employs several ranking methods to create a compromise solution that leverages the strengths of different MCDM techniques. Stakeholders use this method to get a final ranking by computing the weighted mean or product of normalized criterion ratings. The method begins by weighing the different criteria in proportion to their importance, as determined by an expert or statistical procedure, and calculating a combined score for each alternative. Using the CoCoSo method, a recent study assessed renewable energy technologies by considering their investment cost; O&M cost, energy cost, land use, GHG emissions, water usage, technical maturity, efficiency, access to resources, and impact on job creation. The method is effective due to its flexibility in balancing benefits and costs, the use of diverse data, and its ability to rank sustainability policies for informed decision-making.

4. CASE STUDY

4.1. STUDY REGION AND POLICY CONTEXT

This study examines the Republic of Serbia, located in Southeastern Europe, which aims to increase its use of renewable energy and reduce its reliance on fossil fuels. [13-16] A major share of Serbia's electricity is produced by coal, which causes many greenhouse gas emissions and environmental problems. Both what Serbs want and the rules set by other countries lead Serbia to aim for strong increases in renewable energy usage by 2030. The government plans to use incentives and rules to motivate investment in solar, wind, small hydropower and biogas as RES. As resources are limited and the country aims to improve its social, economic, and environmental situation, Serbia is a suitable region for applying a Multi-Criteria Decision-Making (MCDM) approach.

4.2. IMPLEMENTATION OF MCDM

A hybrid combination of the FANMA method and the Weighted Aggregated Sum Product Assessment (WASPAS) was used to assess and rank renewable energy options. The process was initiated by establishing criteria based on what was learned through stakeholder engagement and by reviewing available literature. Ecological impact, cost of building, cost per kilowatt, expected return on investment, and future opportunities in integrating with other energy systems played a significant role in the review. Field research, statistics, and consultations with experts provided the data, which were then adjusted to be comparable across different groups and measures.

The Shannon entropy method was adapted to incorporate fuzzy reasoning, enabling experts and policymakers to weight priorities for each criterion proportionally. Solar power plants, wind power plants, biogas plants and small hydropower plants were then checked against these criteria. The MCDM steps finished with the scores being combined after weighting and normalizing, giving a final ranking of the alternatives. Using a mix of different analytical methods ensured that the results were solid and objective, as it accepted both numerical and descriptive data.

4.3. ANALYSIS OF RESULTS

The investigation revealed that solar energy projects were the most suitable among the renewable energy options reviewed. Among all options, solar power was the most preferred by the public, provided the highest financial gain, and generated the least noise, as these were the key factors considered. Favourable environmental and economic conditions in some regions have helped small hydropower projects emerge as the second-ranked technology, with society focusing on this area. The following wind and biogas projects were ranked using the access to needed resources and the chances of integration at the site as key factors. The results guide energy policymakers in Serbia in their choices. Maximising solar and small hydropower projects helps Serbia achieve a balanced approach that leads to economic gains, reduced environmental harm, and support from the majority of citizens. This case demonstrates that the MCDM framework can guide decisions on allocating subsidies and selecting technologies that can be used in other countries pursuing sustainable energy growth. Other studies in different regions confirm these results, demonstrating the increasing utility of MCDM methods in renewable energy planning.

5. RESULTS AND DISCUSSION

5.1. EVALUATION OUTCOMES

Using the fuzzy MCDM framework with cumulative prospect theory in Malaysia enabled the identification of which renewable energy options people prefer. Solar power was found to be the preferred method for sustainable development, with biomass, wind, and hydropower being the next best options. Solar energy shows the same reliable results in a number of reports because it outshines other energies in important areas such as efficiency, fast payback, cutting carbon dioxide and being well-developed. To illustrate, for example, solar energy is shown as the most efficient (ranks first with 0.85), provides the quickest payback (comes first with 0.90), and emits the lowest CO_2 levels (ranks highest with 0.95). Biomass was praised for providing numerous jobs, although wind and hydropower fell behind due to being relatively new and requiring more space.

TABLE 1 Normalized score of renewable energy alternatives in malaysia

Criteria	Solar	Biomass	Wind	Hydro
Efficiency	0.85	0.70	0.65	0.80
Investment Cost	0.80	0.75	0.60	0.65
Payback Period	0.90	0.70	0.60	0.75
Employment Creation	0.80	0.85	0.70	0.60
CO_2 Emissions	0.95	0.80	0.85	0.90
Land Use	0.75	0.70	0.80	0.65
Technical Maturity	0.90	0.80	0.70	0.85
Public Acceptance	0.85	0.75	0.65	0.80

5.2. SENSITIVITY ANALYSIS

Sensitivity analysis was conducted to determine how the evaluation results are affected by changes in criterion values and prospect data. The results revealed that while the order of alternatives often remains constant, the selected alternative may change significantly if there are major changes in what the decision-maker finds important or their risk attitude shifts. In this way, if emphasis is put on increasing jobs or managing land, biomass or wind might become a more attractive choice. MCDM reliably listed solar energy as the leader, suggesting a trustworthy process for policy decision-making in Malaysia.

5.3. POLICY IMPLICATIONS

The results can guide decisions by Malaysian authorities. Since solar power is growing rapidly, it seems logical for the government to invest in incentives and subsidies for solar projects, which will boost public spending and hasten the country's progress toward its sustainability targets. Officials should include the following in their governing:

- Develop more effective mechanisms in green finance to support solar energy.
- Generate public attention and teach about solar technology to boost capacity in the field.
- Parse and modify policy programs as advancements in technology and the market occur.
- Encourage different sectors to come together and address any issues related to grid connections and land use.

These steps match Malaysia's overall aims for energy transition and may fix an issue with underused renewable energy sources today.

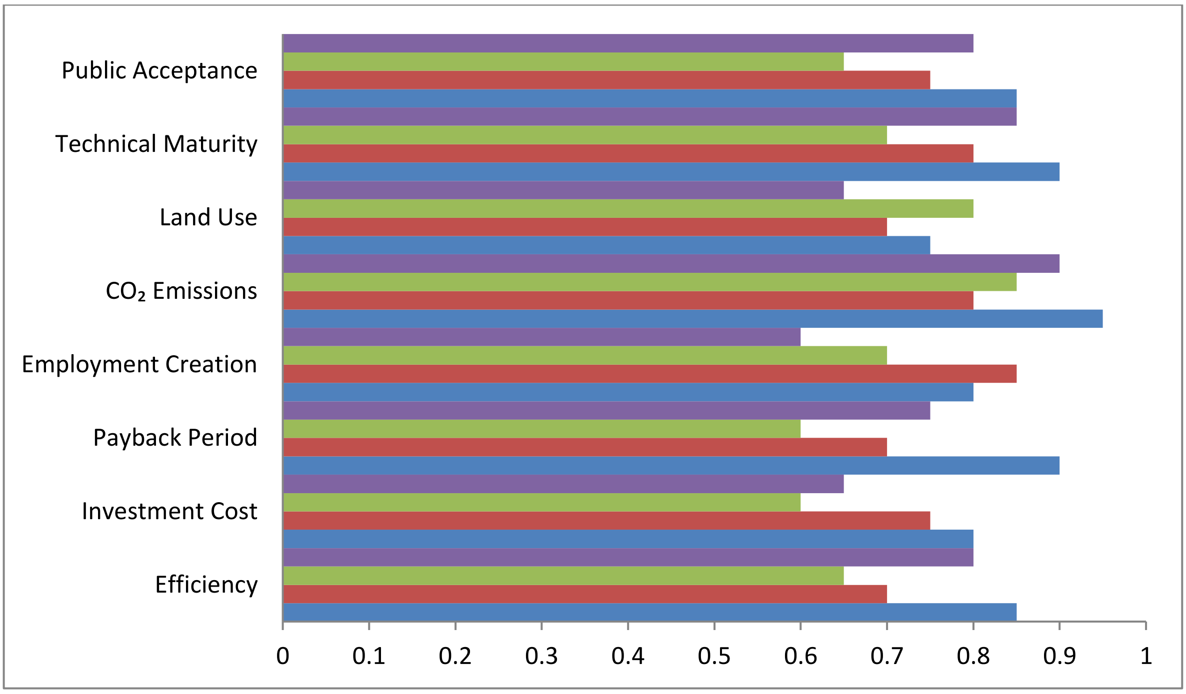

FIGURE 3 Graphical representation of normalized scores of renewable energy alternatives in malaysia

5.4. COMPARISON WITH TRADITIONAL EVALUATION MODELS

Fuzzy MCDM is superior to traditional approaches, such as simple cost-benefit analysis or ranking based on a single criterion. Uncertainty is incorporated, and several aspects (economic, technical, social, and environmental) are considered, along with the diverse preferences of decision-makers. Traditional approaches sometimes overlook factors such as stakeholder views, which can lead to policies becoming less effective over time. Alternatively, when applied in conjunction with cumulative prospect theory, the fuzzy MCDM model can provide more thorough and flexible guidance on strategies for developing renewable energy sources.

6. CONCLUSION

The study demonstrates that a Multi-Criteria Decision-Making (MCDM) model facilitates the determination of the cost-effectiveness of renewable energy subsidies. The approach helps experts to assess and organize various renewable energy options, so that government support matches the best needs and supports environmental goals. Focusing on solar energy is consistently found to be the best option, based on strong data and sensitivity analysis, after which biomass, wind, and hydropower are ranked. This demonstrates that a whole-system approach with reliable data plays a key role in directing important steps and improvements in renewable energy.

This proves that flexible and responsive regulations are essential as the market and technology evolve, as well as in response to changing stakeholder needs. Experts advise policymakers to explore ways to improve the distribution of subsidies, gather more input from those affected, and utilize MCDM to make better decisions. Such frameworks will not only help transition to greener energy but also bring additional social and economic benefits from using renewable energy, thereby supporting both national and international sustainability efforts.

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