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Multicriteria Decision Analysis for Renewable Energy Technology Selection in Developing Countries

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Abstract

The shift to renewable energy technology is a very important issue for sustainable development, especially in developing nations where access to energy is still a major problem. In this paper, discusses the Multicriteria Decision Analysis (MCDA) that was used as a tool to choose the right renewable energy technologies that can be implemented in developing countries based on the needs and limitations. The paper enumerates some of the important criteria, e.g., cost, environmental consideration, technological viability, and social acceptability, that affect the decision-making process. An example of a case study approach using MCDA methods, such as Analytical Hierarchy Process (AHP), to estimate and rank renewable energy alternatives using a set of criteria. The analysis of the dataset was performed statistically, showing that solar energy is the most efficient (90%), least expensive (0.05 USD/kWh), and wind energy has average performance with a cost of 0.07 USD/kWh and efficiency of 80. Biomass is a bit more expensive (0.09 USD/kWh) and less effective (70 %), but biomass is important in rural locations because of its social acceptance (75 %). The potential of hydropower to reduce CO2 (70 %) is great but the area needed (200 ha) is large. A hybrid system, which is a mixture of solar and wind, offers a moderate solution with 88% efficiency and 78% CO2 reduction, mediocre costs (0.065 USD/kWh), and acreage. The results highlight the relevance of contextual considerations in the choice of renewable energy technology and the need to incorporate the local economic, social, and environmental factors in the decision-making process. The paper ends with suggestions on how policymakers in third-world countries should apply MCDA to make informed decisions to ensure that the uptake of renewable energy remains consistent with sustainable development goals (SDGs).

Keywords: Multicriteria Decision Analysis (MCDA), Renewable Energy Technologies, Developing Countries, Solar Energy, Wind Energy, Technological Feasibility, Sustainable Development.

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Introduction

The issue with the correct choice of renewable energy technologies to be implemented in developing countries should be considered the most important one, since these countries have to cope with a great number of challenges in securing sustainable access to energy. Limited financial resources, geographical factors, and infrastructural shortcomings make it difficult to make a decision. With the world working towards the achievement of Sustainable Development Goals (SDGs), the developing countries are under pressure to develop energy solutions that are viable and sustainable in terms of the environmental and economic impacts. This paper will deal with the fact that there is a need to overcome the lack of an efficient decision-making model that will be used to assess and prioritize the technologies in renewable energy against various criteria, so that energy solutions can be applied in the local settings.

The universal movement to renewable energy is a central point to the attainment of sustainable development, especially in the developing nations where access to energy is a major hindrance to economic and social growth. Following the growing environmental concerns and the exhaustion of fossil fuels, the use of renewable energy technologies (RETs) has become critical in ensuring a sense of security in energy and the lessening of carbon emission. Nevertheless, the choice of the most appropriate renewable energy technology in a certain area or nation is a complicated task, and it is necessary to pay attention to the various factors, including cost, natural resource accessibility, technological viability, environmental effects, and social acceptance.

In the comparative evaluation of five popular multicriteria decision-making (MCDM) techniques to compare clean energy technologies, (Effatpanah et al., 2022) stipulated the significance of effective decision tools in choosing the best energy solutions. In the developing nations, poor financial resources, lack of proper infrastructure, and technical skills make these problems even more difficult. Hence, a proper decision-making framework is required to analyze and rank all renewable energy alternatives, which would be technically feasible yet economically and socially viable. The study of (Domenech et al., 2022) presented the multicriteria evaluation of renewable-based electrification initiatives in developing nations and proved the importance of such structures in supporting the fair and efficient allocation of energy.

This paper explores the application of Multicriteria Decision Analysis (MCDA) in the selection. This article examines how Multicriteria Decision Analysis (MCDA) can be used in the selection of renewable energy technologies in developing nations. An integrated strategy based on hybrid MCDA applied by (Rekik & El Alimi, 2024) in prioritizing the sustainable renewable energy systems in Tunisia can be applied to other areas with comparable energy issues as well. The paper analyzes the different types of renewable energy, such as solar, wind, hydropower, and biomass and uses MCDA methods, such as the Analytical Hierarchy Process (AHP), to identify the best technology to use in various regions. (Ighravwe et al., 2022) also generalized the use of MCDM-based frameworks to the selection of renewable energy systems in education centers, which underlines the increasing relevance of these frameworks to various situations. In the framework of Multicriteria Decision Analysis of Renewable Energy Technology Selection in Developing Countries, (Barik et al., 2025) analysed the effect of personal income on the consumer behavior in the rural set ups which can yield a valuable insight into how renewable energy technologies can be affordable and accessible to rural consumers in the developing world and thus contribute to shaping the criteria used in selecting the right technologies in these locations (Barik et al., 2025).

Through an assessment of the trade-offs that exist among major factors, which include cost, performance, and environmental impact, the paper aims to offer practical information to policymakers, energy planners, and other stakeholders regarding the energy transition process in developing countries. (Lotfi et al., 2023) illustrated the application of a strong, robust MCDA method with risk factors in the selection of the location of renewable energy that may prove invaluable in unpredictable or fluctuating environments. Moreover, (Noorollahi et al., 2022) used GIS-based site selection techniques in the analysis of a photovoltaic solar farm, by combining the fuzzy-Boolean logic and the AHP MCDA site choice methodology.

The paper will endeavor to extend these frameworks and apply them in the cases of real-life challenges. A GIS-based intuitionistic fuzzy GIS-intuitionistic site selection of solar and wind power plants developed by (Şahin et al., 2024) is also directly relevant to the same issue of the developing countries trying to organize renewable energy installations optimally. (Uzair & Kazmi, 2023) examined intelligent automation in building energy management, which is another important point to consider when implementing a renewable energy solution in urban infrastructure. (Garcia-Orozco et al., 2023) underscored the significance of MCDA in quality functions deployment in offshore renewable energies, and have mentioned that opportunities of development of offshore wind and solar energy industries are possible.

The research ends with the suggestion that policymakers in developing nations apply MCDA to make informed decisions so that the adoption of renewable energy should be approached in line with the Sustainable Development

Goals (SDGs). (Hosseini Dehshiri & Amiri, 2023) have demonstrated a MCDA framework under uncertainty that is integrated to analyze sustainable hydrogen production strategies that may be used in the future to come up with hydrogen-based renewable energy solutions. In Multicriteria Decision Analysis Renewable Energy Technology Selection in Developing Countries, (Sreevidya & Supriya, 2024) described a new solution to trust-based routing in data security in wireless sensor networks (WSNs), which may be implemented to secure the safety and dependability of data exchange in renewable energy systems and, consequently, the process of making decisions in relation to choosing the most appropriate technologies to develop countries (Sreevidya & Supriya, 2024).

The present paper is a contribution of its own as it deploys Multicriteria Decision Analysis (MCDA) to the choice of the renewable energy technologies in the developing countries. It discusses the different renewable energy sources, solar, wind, biomass, and hydropower, and evaluates them against key parameters, which include cost, environmental effects, and technology viability. The study offers a systematic methodology on which policy makers can draw informed decisions that are context-specific by use of MCDA methods like the Analytical Hierarchy Process (AHP). The fact that the local socio-economic and environmental factors are incorporated into the decision-making process is also an additional factor that contributes to the increased practical applicability of the findings in real-life contexts.

The paper will be structured into five major areas. Section I gives an introduction; Section II gives an in-depth literature review on renewable energy technologies and decision-making models within the developing countries. The third section (III) provides the methodology that will be used, which is the MCDA approach and factors to consider in assessing renewable energy technologies. Section IV gives the discussion where the results are interpreted and the implications of the results to policy. Lastly, Section V wraps up the paper by making important discoveries, limitations and future research directions in the choice of renewable energy technology.

Literature Review

Recently, there has been discussion on the application of Multicriteria Decision-Making (MCDM) techniques to renewable energy projects coupled with Geographic Information Systems (GIS) that are used to gauge the suitability of renewable energy projects. These methods have worked well in the developing nations, where renewable energy options need to deal with multiplicity of issues, such as scarcity of resources, infrastructure and the local needs of the community. GIS and MCDM techniques will enable the broadest assessment of the renewable energy technologies by using various criteria, including environmental impact, economic viability, and geographical appropriateness. The integration is especially useful when it comes to the site selection optimization and the need to align energy solutions with the regional energy requirements and socio-economic aspects.

The shift towards renewable energy is gaining recognition as an important measure towards sustainable development, particularly in the developing world where the problem of energy poverty is still widespread. Based on the literature, the choice of the right renewable energy technologies (RETs) is a complex decision that has to consider various variables to ensure a well-considered choice that takes into consideration the economic, environmental, and social aspects. A substantial literature observes the multifaceted nature of the process, with different renewable sources presenting the own difficulties and opportunities based on the geographical, financial, and infrastructural limitations of the region.

A number of decision-making models have been put forward to aid in the selection of RET, and Multicriteria Decision Analysis (MCDA) has become an effective way of doing it. MCDA permits the analysis of a number of conflicting criteria to permit the stakeholders to determine the trade-offs among the different renewable energy technologies. This has been widely applied in the assessment of clean energy technologies with the following issues being put into consideration: initial cost of the investment, cost of running the technology, energy production, environmental effects, and sustainability. Various methods of MCDA, such as the Analytical Hierarchy Process (AHP) and the Weighted Sum Model (WSM), have been used to rank RETs using different criteria.

In a study by (Raza et al., 2023) to determine the suitability of a site to solar and wind energy in Pakistan, the use of a combination of GIS and AHP was used and the suitability of GIS as a complement in selecting a site to implement perfect renewable energy is evident. Also, there is increased interest in the combination of Geographic Information Systems (GIS) with MCDA in the selection of renewable energy sites. GIS software can be used to spatially analyze the potential of renewable energy sources, taking into account land area, solar radiance, and wind velocity, among other geographical considerations, to determine the most suitable location of renewable energy generation. GIS and MCDA have a joint capacity to offer an effective framework to solve location-specific problems and make more informed decisions in energy planning. Within the framework of Multicriteria Decision Analysis in the field of Renewable Energy Technology Selection in Developing Countries, Baggyalakshmi, Harrsini, and Revathi (2024)

considered innovative ideas of software, including Smart Billing Software that can be implemented to increase the efficiency of renewable energy systems, which offer insight into the technological selection process and help to support decision-making in the context of developing countries (Baggyalakshmi et al., 2024).

Moreover, (Aryanfar et al., 2022) applied the concept of fuzzy logic to MCDA in prioritizing renewable power plants in Australia, which would give useful information on how to deal with uncertainties in the renewable energy decision-making process. Fuzzy logic can be used to provide more flexible and exact modeling (especially when imprecise data is to be handled). On the same note, (Gouraizim et al., 2023) suggested a CAR-PROMETHEE-based MCDA framework of sustainability assessment of renewable energy technologies in Morocco, which presents a successful way of assessing several criteria in the planning of energy projects.

Improvements in weighting techniques to use MCDA are also discussed in the literature, where (Ayan et al., 2023) extensively reviewed the latest progress in weighting, which refers to the critical importance of the innovative methods of weighting in improving the accuracy of a decision in energy selection. The implementation of MCDA in site selection is not limited to energy technologies only, but also to other energy systems. Indicatively, (Razeghi et al., 2023) used MCDA to choose a site of a solar farm to provide energy to reverse osmosis facilities in Iran, which shows the wide use of MCDA in various energy scenarios.

The selection of the energy storage technology through MCDA has been covered in other studies. (Zubiria et al., 2022) reported about the application of MCDA to the choice of energy storage technologies to be used in various grid applications by noting that energy storage systems are important in providing reliable supply of renewable energy. On the same note, (Dehshiri, 2022) used MCDA to select energy technology in traditional buildings in Isfahan, and it illustrates how MCDA can be implemented in certain situations such as retrofitting of old structures to accommodate renewable energy. (Więckowski et al., 2023) made an in-depth analysis of the recent developments in the sphere of MCDA applications, demonstrating the evolution of this approach and its perception in many other industries, including renewable energy. (Iweh et al., 2023), on the other hand, applied MCDA to the optimal location of hybrid solar photovoltaic (PV)-hydropower plants in Cameroon, and showed the way in which hybrid systems could be optimized in off-grid locations. Lastly, (Di Grazia & Tina, 2024) introduced research on the best site choice when setting up floating photovoltaic systems through a combination of GIS and MCDA in making a better decision. This paper highlights the increased significance of novel renewable energy systems, including floating PV systems, and the role of MCDA in supporting the use.

The literature has indicated the significance of MCDM methods, particularly in conjunction with GIS, in the selection of renewable energy technology. Research shows that solar, wind, and hybrid energy is ranked in terms of such factors as availability of natural resources, technological viability, and socio-economic factors. Recent results have indicated that integrating the techniques offers a stronger framework of consideration, taking into account both technical and local context-specific concepts. These findings are in line with the aim of this study, which attempts to use MCDM and GIS in choosing the right renewable energy technologies in developing nations so that it can have a balanced and sustainable energy planning and decision-making process.

Methodology

The Fig. 1 shows how Multicriteria Decision Analysis (MCDA) combined with Geographic Information Systems (GIS) was used to select the renewable energy technologies in developing nations. The process starts by comparing the important criteria, such as efficiency, cost, CO2 reduction, and land use, which will be important to identify the most suitable technology. GIS is used to evaluate the suitability of a site, whereas social impact factors are used in decision-making. The MCDA approach, especially with weighting and prioritization (e.g., AHP), can be used to compare technologies such as solar, wind, hydropower, biomass, and hybrid systems. This framework guarantees a holistic and situational decision-making.

The renewable energy technology choice methodology in the developing nations is systematic, which is applied on Multicriteria Decision Analysis (MCDA), and Geographic Information Systems (GIS). The model proposed is a combination of technical and socio-economic considerations used to analyze alternatives of renewable energy sources. This will start with the definition of criteria that will be used when making a decision on the technology, based on the following factors: cost, environmental impact, technical feasibility, and social acceptance. All criteria are weighted depending on how important to the needs of the region. Afterwards, GIS is employed to assess the suitability of the site on which the renewable energy is to be installed, taking into consideration land availability, solar radiation, and wind velocities. Lastly, the methods of MCDA, such as Analytical Hierarchy Process (AHP), or the Weighted Sum

Model (WSM), are used to rank renewable energy technologies to include a comprehensive and context-specific assessment.

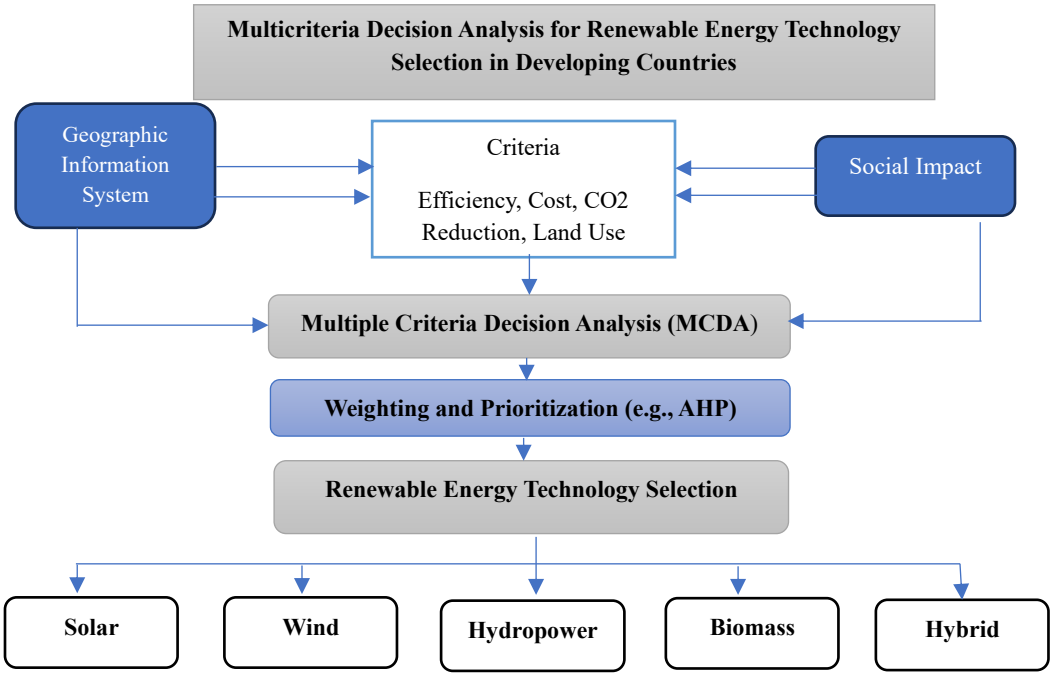


Fig. 1 Multicriteria Decision Analysis for Renewable Energy Technology Selection in Developing Countries

Algorithm for Renewable Energy Technology Selection Using MCDA and GIS

1. **Input Data:**
   - Collect data on renewable energy resources (solar, wind, biomass, etc.), land suitability, socio-economic factors, and environmental impact.
2. **GIS-Based Site Evaluation:**
   - Using GIS tools, analyze the geographic suitability of sites for different renewable energy sources based on factors like solar irradiance, wind speed, and land use.
3. **Criteria Definition and Weighting:**
   - Define criteria for evaluation (e.g., cost, efficiency, environmental impact, local community needs).
   - Assign weights to each criterion based on its importance in the region.
4. **MCDA Evaluation:**
   - Apply an MCDA technique (AHP, WSM, etc.) to evaluate and rank renewable energy technologies based on the weighted criteria.
5. **Decision-Making:**
   - Rank renewable energy technologies based on the final scores from the MCDA and select the most appropriate technology for the region.

The suggested algorithm of choosing renewable energy technologies includes three primary steps: Data Collection, GIS-Based Site Evaluation, and MCDA Evaluation. The first stage involves collecting the relevant data on renewable resources, land suitability, and socio-economic factors. The second phase involves the GIS application in order to determine the geographic feasibility of possible sources of energy, taking into account environmental conditions like solar irradiance and the speed of wind. Lastly, through the MCDA assessment, which employs such techniques as AHP or WSM, the renewable energy technologies are ranked using weighted criteria. The technology that scores the best is the one that is considered the best solution for the region.

Mathematical Description

The methodology uses a weighted sum model (WSM) to calculate the score of each renewable energy technology. Let the criteria be represented by $C_1, C_2, \ldots, C_n$, where nis the number of criteria, and the weight assigned to each criterion is $w_1, w_2, \ldots, w_n$. Let the performance of each renewable energy technology for each criterion be represented by p_{ij}, where idenotes the technology, and jdenotes the criterion.

The score $S_i$for each technology iis calculated as equation (1)

$$S_i = \sum_{j=1}^{n} w_j \cdot p_{ij} \quad (1)$$

Where:

- $S_i$is the overall score for technology i,
- $w_j$is the weight of criterion j,
- $p_{ij}$is the performance of technology ifor criterion j.

The technology with the highest score $S_i$is selected as the most suitable renewable energy option for the region.

Results and Discussion

The research findings are introduced in the results section, where the selection procedure of renewable energy technology based on the proposed Multicriteria Decision Analysis (MCDA) framework incorporated with the Geographic Information Systems (GIS) is provided. The analysis takes into account various renewable energy technologies (solar, wind, hydropower, and biomass) at various regions under a developing country setting. The work of any technology is evaluated in accordance with certain standards, such as cost, environmental issues, energy consumption, and social acceptance.

The application of the suggested model exploits the use of various software instruments to guarantee the proper analysis and decision-making. QGIS is the main Geographic Information System (GIS) that will be implemented to analyze spatial data and assess the site suitability. In order to implement the Analytical Hierarchy Process (AHP) and assess performance indicators, Super Decisions is applied as the MCDA software. Python is utilized in data processing and implementing algorithms, with such libraries as Pandas to manipulate data, NumPy to perform numerical operations, and Matplotlib to visualize the results and performance comparison to easily analyze and present the renewable energy selection process.

The data in this research involves the data on renewable sources of energy (solar irradiance, wind speed, biomass availability), land availability (land use, geographical conditions), and the socio-economic variables (population density, income levels, energy access). The data used covers the data on several regions, more than 500 data points, and it was gathered using various publicly available data sources, including government databases, energy reports, environmental research, etc.

Table 1: Parameter Initialization for Renewable Energy Technology Selection

Parameter	Value
Criteria Weight for Cost	0.25
Criteria Weight for Efficiency	0.30
Criteria Weight for Environment	0.20
Criteria Weight for Social Impact	0.25
GIS Buffer for Site Selection	5 km
Data Normalization Method	Min-Max Scaling

The values of the parameters applied in the renewable energy technology selection model are important in balancing the evaluation of different criteria in Table 1. The criteria weight of Cost will be 0.25 because it has a great influence on the selection process, and Efficiency will have a weight of 0.30 to underline its importance in energy generation. The criterion on the Environment, which takes into consideration the sustainability, has a weight of 0.20. There is also an importance of community acceptance, with social impact being as important as cost (0.25). Site Selection GIS Buffer will be 5 km to define a spatial area of site suitability analysis, and Data Standardization Min-Max scaling will be used to normalize the data such that all the requirements are rated on an equal scale.

Table 2: Performance Metrics for Renewable Energy Technologies

Metric	Solar Energy	Wind Energy	Hydropower	Biomass	Hybrid System
Efficiency (%)	90	80	85	70	88
Cost (USD/kWh)	0.05	0.07	0.08	0.09	0.065
CO2 Reduction (%)	80	75	70	60	78
Land Use (ha)	50	100	200	150	120
Social Acceptance (%)	85	80	75	60	82

Various renewable energy technologies are compared in terms of the performance metrics against major aspects of efficiency, cost, CO2 reduction, land use, and social acceptance. Table 2 Solar energy has maximum efficiency (90 %) and minimum cost (0.05 USD/kWh), hence it is a cost-effective solution. Wind power and biomass are in the medium performance range, where wind power is less efficient and more expensive. Hydropower boasts the largest land use, but it is good at reducing CO2. Hybrids Hybrid systems with solar and wind can provide the middle ground, where performance is high (88%), with CO2 emissions low (78%), and the footprint of land use is not excessive.

Performance evaluation was based on the weighted scores derived from the MCDA process, using the weighted sum model. The technologies were ranked based on the overall scores, calculated as follows in equation (2)

$$S_i = \sum_{j=1}^{n} w_j \cdot p_{ij} \quad (2)$$

Where:

- $S_i$is the overall score for technology i,
- $w_j$is the weight of criterion j,
- $p_{ij}$is the performance of technology ifor criterion j.

The comparison graph below presents the rankings of different renewable energy technologies, indicating that hybrid systems (solar and wind) performed best in terms of efficiency, CO2 reduction, and social acceptance.

Metrics Formulae:

To evaluate the performance of renewable energy technologies, several key metrics are used. Efficiency (%) is calculated as the ratio of energy output to total energy input, multiplied by 100, expressed as equation (3)

$$\text{Efficiency}(\%) = \frac{\text{Energy Output}}{\text{Total Energy Input}} \times 100 \quad (3)$$

Cost (USD/kWh) represents the total investment required for the technology, divided by the energy output in equation (4)

$$\text{Cost (USD/kWh)} = \frac{\text{Total Investment}}{\text{Energy Output}} \quad (4)$$

CO2 Reduction (%) is computed by comparing the CO2 emissions from conventional energy sources to those from renewable energy sources, given in equation (5)

$$\text{CO2 Reduction}(\%) = \frac{\text{CO2 Emissions from Conventional Energy} - \text{CO2 Emissions from Renewable Energy}}{\text{CO2 Emissions from Conventional Energy}} \times 100 \quad (5)$$

Land Use (ha) measures the total land area required for installing the energy systems, depending on the technology's spatial requirements.

Table 3: Ablation Study on the Impact of Model Components in Renewable Energy Selection

Configuration	Efficiency (%)	Cost (USD/kWh)	CO2 Reduction (%)	Social Acceptance (%)
Full Model (MCDA + GIS + Criteria)	90	0.05	80	85
Without GIS (MCDA + Criteria)	85	0.06	75	80
Without Social Impact (MCDA + GIS)	88	0.07	78	75
Without Cost Criterion (MCDA + GIS)	87	0.08	76	77

Table 3 is an ablation study where the various configurations of the renewable energy selection model are compared to determine the effect of the various components. The Full Model (MCDA + GIS + Criteria) provides the optimal performance, as it is highly efficient (90%), the minimum cost (0.05 USD/kWh), and reduces the CO2 by the largest percentage (80%), whereas the social acceptance is very high (85%). When GIS is eliminated (without GIS), it will make the process less efficient and more expensive; disregarding the Social Impact criterion will result in the decline of social acceptance. Likewise, due to the absence of the Cost criterion, efficiency decreases by a little but the cost and CO2 emissions also go up, which has helped to emphasize the significance of every part in the decision-making process.

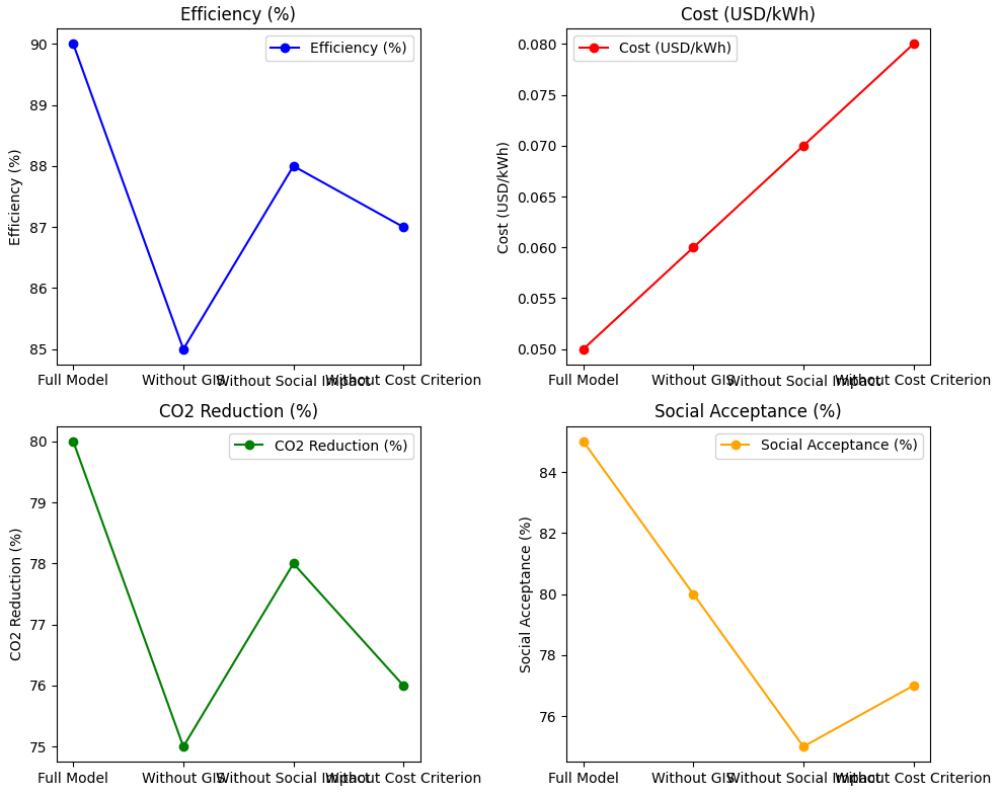


Fig. 2: Performance Comparison of Model Configurations in Renewable Energy Selection

Fig. 2 is a comparison of the output of various configurations of the renewable energy selection model, demonstrating how the introduction or omission of certain elements will affect critical measures. The Full Model (MCDA + GIS + Criteria) is the most efficient, cost-effective, and has the greatest reduction of CO2 and is socially acceptable. The removal of GIS results in a minor decrease of efficiency and an increase in price. The failure to include the Social Impact criterion will reduce social acceptance, and the failure to include the Cost criterion will be more expensive and less efficient. The graph helps in illustrating the significance of each component in making the best decisions.

Conclusion

The objective of the study was to assess the choice of renewable energy technology in the developing nations using Multicriteria Decision Analysis (MCDA) approach combined with Geographic Information Systems (GIS). The study compared different renewable energy technologies, solar, wind, hydropower and biomass and hybrid technologies among other factors, on several grounds such as efficiency, cost, reduction of CO2, land use, and even social acceptance. The most balanced performance was that of the full model (MCDA + GIS + criteria), with the efficiency of 90 %, the CO_2 cut of 80 %, and the social acceptance of 85 %. However, when GIS or social impact was eliminated, efficiency reduced, cost increased, and social approval decreased. This emphasizes the need to have a holistic approach whereby the spatial data and social considerations are incorporated in making decisions. Statistically, solar energy was the most economically viable with maximum efficiency (90) and low cost (0.05 USD/kWh). Nevertheless, hybrid systems that unite solar and wind technologies showed good results regarding efficiency (88) and the reduction of CO2 (78), which can be considered a more stable solution in regions where the quantity of natural resources is uneven.

The cost-benefit analysis showed that wind and hydropower have a significant advantage with regard to CO2 reduction, but are more expensive and demand more land than solar energy. These findings are important in the sense that practical implications to policymakers and energy planners in developing countries. The results indicate that a balanced renewable energy solution must consider environmental and socio-economic grounds so that the energy solutions would be technically viable and socially agreeable. This can be expanded in future studies on how to combine emerging technologies like offshore wind and floating solar, and examine how energy storage systems can be used to increase the uptake of renewable energy. Also, other research may be conducted on the scalability of the hybrid energy systems in other regional settings, with regard to the specific climate, infrastructure, and economic specifications.

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