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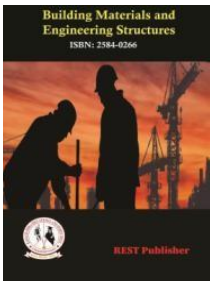

Strategic Planning of Renewable Energy Opportunities in India Through Multi-Criteria Analysis Using Grey Relational Analysis

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Abstract: *In India, the rapid growth in population and the rising per capita energy consumption present challenges that require the effective utilization of existing energy resources. Currently, a major portion of India's energy needs is fulfilled by non-renewable sources, which strains the economy and poses significant environmental risks. To tackle this issue, the Indian government and state agencies are actively encouraging the adoption of renewable energy sources. Similar to other developing nations, India is experiencing an increasing demand for energy due to its expanding population and economy. However, unlike its limited domestic oil and natural gas reserves, India possesses abundant renewable energy resources. The country is looking to increase its use of renewable energy sources in the future. This study proposes a combined approach using Benefits, Opportunities, Costs, and Risks (BOCR) analysis with Multi-Criteria Decision Making (MCDM) to assess India's energy situation and identify the best renewable energy options. BOCR analysis provides a thorough evaluation of the country's energy challenges and opportunities, while MCDM considers both tangible and intangible factors in decision-making. The GRA models have progressed from early versions that focused on the relationship coefficients of individual points in sequences to more generalized models that take into account integral or overall perspectives. Initially, these models focused on measuring similarity primarily based on nearness, but they have since evolved to consider both similarity and nearness. The scope of research has broadened from analysing relationships among curves to curved surfaces, then to relationships in three-dimensional space, and even to relationships among super surfaces in n-dimensional space. The study concludes that hydroelectric power is the most optimal renewable energy source for India.*

Key words: *renewable source, BOCR, Multi-Criteria Decision Making, GRA methods*

1. INTRODUCTION

Energy is a crucial commodity that drives economic growth. Its supply uncertainty can disrupt economic activities, particularly in developing countries. India, with 18% of the global population, consumes 6% of the world's primary energy. Its energy consumption grew from 15,146 Peta Joules in 2005-2006 to 20,471 Peta Joules in 2013-2014, reflecting a substantial annual growth rate of 7.36%. The country is considered a developing nation due to factors such as its large population, projected to reach around 1.6 billion by 2050, and the majority of its labour force being employed in agriculture (60%), services (28%), and industry (12%). While agriculture contributes 28% to India's GDP, services and industry contribute 54% and 18%, respectively. Despite being classified as a developing country, India shows promise of transitioning to a developed nation over time, with a growing economy and improvements in living standards. India's GDP grew by 9.4% in 2006–07, positioning it among the world's fastest-growing economies. It is the eleventh largest energy producer globally, contributing 2.4% to the world's total annual energy production, and the sixth largest energy consumer, accounting for 3.3% of the world's total annual energy consumption. However, India remains a net energy importer due to a substantial gap between oil production and consumption.

The methodology used in this study to identify and prioritize the primary obstacles to energy generation from pine needles involved gathering factors affecting energy generation from pine needles from existing literature and expert opinions obtained through personal interviews and focused group discussions. A questionnaire was created using these inputs and refined after consulting with experts. Data was collected through in-depth interviews with 65 experts from the forest department and academia, who completed the questionnaires. Judgmental sampling was employed to choose the respondents, as large samples can introduce inconsistencies in the Analytic Hierarchy Process (AHP) used in this study. The research focuses on identifying and prioritizing the key challenges of using pine needles for energy generation in Uttarakhand, India, to tackle climate change. The study aims to classify these barriers and prioritize them using a MCDM (multi-criteria decision-making) technique, particularly the Analytic Hierarchy Process (AHP) with fuzzy logic. This approach intends to provide valuable insights for policymakers and stakeholders. This study is notable for its comprehensive approach to identifying and prioritizing barriers to energy generation from pine needles in Uttarakhand, filling a notable gap in existing research. The methodology includes sensitivity analysis to ensure the reliability of the results. Furthermore, the paper explores Grey Relational Analysis (GRA) models and their use in assessing the similarity and nearness of data sequences. It emphasizes the importance of differentiating between these concepts in GRA models, as suggested by researchers in the field One of the primary challenges in MCDM (multi-criteria decision-making) is to assign priority, importance, and weight to various criteria when evaluating different choices. Grey Relational Analysis (GRA), a commonly used MCDM technique, effectively addresses this challenge. GRA enables the incorporation of both objective and subjective factors from decision makers into the decision-making process.

2. MATERIALS AND METHODS

The Indian government is striving to decrease the nation's reliance on imported energy. With inadequate domestic oil and natural gas reserves to meet demand, ensuring energy supply security hinges on maintaining a variety of energy sources, with a focus on renewable energy (RE) due to India's ample reserves. Renewable energy (RE) has both local and global impacts. It can improve air quality and reduce greenhouse gas emissions and acid rain, often displaced by fossil fuel-based energy. The model prioritizes renewable energy alternatives and is at the top of the control hierarchy, which includes four subnetworks: benefits, opportunities, costs, and risks, illustrating the relationships among their clusters and elements. The expert team determined that the BOCR factors vary in importance and included five strategic criteria in the model to establish weights for the BOCR factors. These criteria, identified through a literature review, are Technology (T), Security (S), Economy (E), Global Effects (GE), and Human Wellbeing (HW). The "Technology" criterion includes assessing technical feasibility, reliability, continuity, predictability of local agents' performance, and local technical expertise. "Economy" involves evaluating the economic value of sources, project implementation costs, and the availability of national funds. The literature review indicates that while several studies have prioritized renewable resources in Middle Eastern countries using multi-criteria decision-making analyses, there is a significant gap in comprehensive studies that simultaneously consider and prioritize most potential renewable resources and technologies in India. Furthermore, studies focusing on prioritizing renewable technologies in Iran have not extensively addressed climate zones. Additionally, there is a lack of comparison regarding the performance of hybrid multi-criteria decision-making models in these studies.

3. GREY RELATIONAL ANALYSIS METHOD

Grey Relational Analysis (GRA), first proposed by Deng in 1989 and further refined in 2002, is a valuable tool in solving MCDM problems. GRA has been successfully applied in resolving numerous MCDM issues, serving as an impact evaluation model that examines the correlation between series. It falls into the category of data analytic or geometric methods. Researchers typically select the target series, based on the study's objective, as the reference series. The primary objective of GRA is to ascertain the relationship between the reference series and the comparison series. The Grey Relational Analysis (GRA) method involves several steps to evaluate and rank alternatives based on their relation to a reference series. First, the decision matrix is normalized to ensure consistency across different criteria. Next, a reference series, denoted as R0, is established. A distance matrix is then created to measure the distance between each alternative and the reference series. Using this information, grey relational coefficients (nij) are calculated to quantify the relationship between each alternative and the reference series. These coefficients are used to estimate the grey relational grade (ci) for each alternative, with higher values indicating a stronger relation to the reference series. Finally, the alternatives are ranked based on their grey relational grades, with higher values indicating a better alternative. This approach enables decision-makers to impartially evaluate and prioritize alternatives based on their performance in relation to a reference series.

4. RESULTS AND DISCUSSION

TABLE 1. Prioritizing Renewable Energy

	Benefits	Opportunities	Costs	Risks
Technology	1.00	0.85	0.40	0.10
Economy	1.00	0.90	0.60	0.25
Security	0.75	0.80	0.50	0.10
Global effect	1.00	0.90	0.20	0.20
Human wellbeing	1.00	0.90	0.40	0.20

Table 1 presents a dataset that evaluates various aspects of implementing renewable energy sources. The benefits of these technologies are rated highest for technology and economy, with scores of 1.00, indicating maximum benefit. These aspects offer substantial opportunities for improvement as well, with technology scoring 0.85 and economy scoring 0.90. However, the costs associated with these implementations are not insignificant, with technology, economy, and human wellbeing scoring 0.40, 0.60, and 0.40 respectively. Additionally, there are risks involved, albeit relatively lower compared to the benefits, with security scoring 0.10, global effect scoring 0.20, and human wellbeing scoring 0.20. This dataset highlights the multifaceted nature of renewable energy adoption, where benefits and opportunities must be balanced against costs and risks.

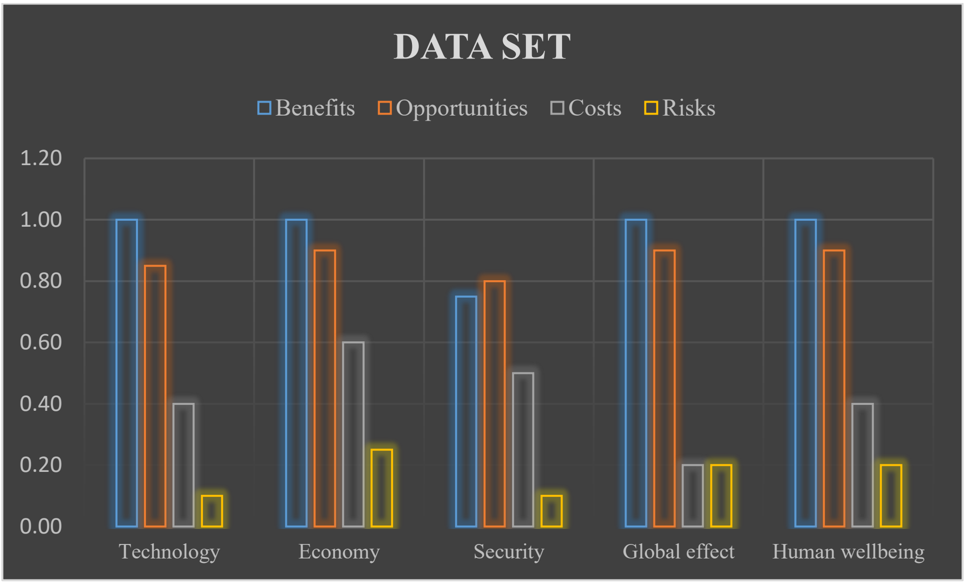

FIGURE 1. Prioritizing Renewable Energy

The Figure 1 provided dataset compares five alternatives across four criteria: Benefits, Opportunities, Costs, and Risks. Technology, Economy, Security, Global effect, and Human wellbeing are evaluated based on their performance in these criteria. This analysis can help in understanding the relative strengths and weaknesses of each alternative in different aspects, aiding decision-making processes.

TABLE 2. Normalized Data

	Benefits	Opportunities	Costs	Risks
Technology	1.0000	0.5000	0.5000	1.0000
Economy	1.0000	1.0000	0.0000	0.0000
Security	0.0000	0.0000	0.2500	1.0000
Global effect	1.0000	1.0000	1.0000	0.3333
Human wellbeing	1.0000	1.0000	0.5000	0.3333

Table 2 provides a normalized view of the data, representing the relative importance of each criterion for selecting renewable energy sources. In this table, the highest normalized score of 1.0000 is assigned to criteria where maximum benefit or opportunity is perceived. For instance, the economy criterion receives a score of 1.0000 for both benefits and opportunities, indicating its critical importance. Conversely, criteria with lower scores, such as security and global effect for benefits and opportunities, suggest lower perceived importance. The normalization process helps to standardize the data, allowing for a more objective comparison of different criteria when prioritizing alternative renewable energy sources.

TABLE 3. Deviation sequence

	Benefits	Opportunities	Costs	Risks
Technology	0.0000	0.5000	0.5000	0.0000
Economy	0.0000	0.0000	1.0000	1.0000
Security	1.0000	1.0000	0.7500	0.0000
Global effect	0.0000	0.0000	0.0000	0.6667
Human wellbeing	0.0000	0.0000	0.5000	0.6667

Table 3 illustrates the deviation sequence, highlighting the variations in importance among the criteria for selecting renewable energy sources. A deviation score of 0.0000 indicates that the criterion aligns closely with the overall trend, while a score of 1.0000 signifies a significant deviation. In this table, the economy criterion deviates the most, scoring 1.0000 for costs and risks, indicating a substantial difference in perceived importance compared to the overall trend. On the other hand, technology shows a moderate deviation, with a score of 0.5000 for opportunities, suggesting a somewhat different perception of its importance in comparison to the other criteria. These deviations provide valuable insights into the nuances of decision-making processes related to renewable energy sources, helping stakeholders prioritize criteria based on their specific context and objectives.

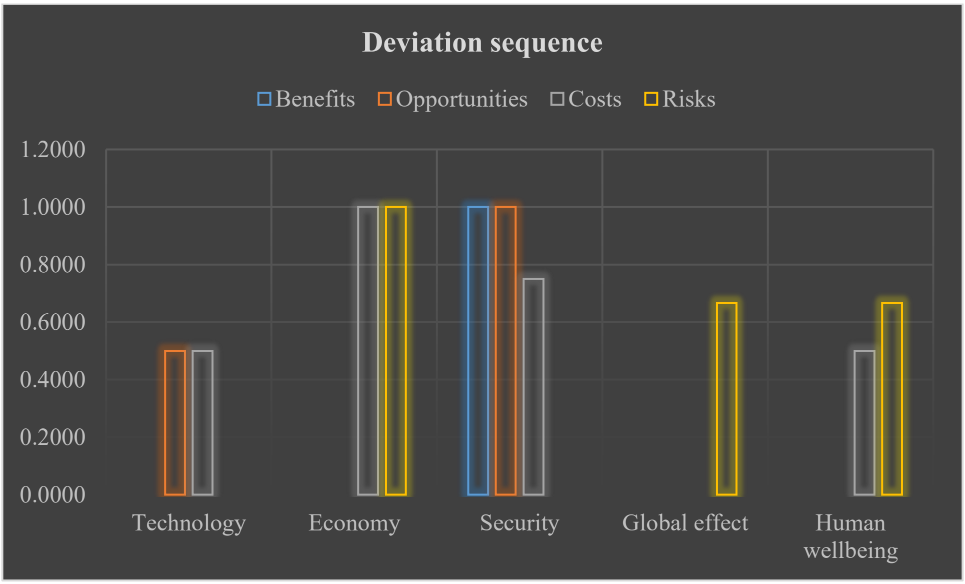

FIGURE 2. Deviation sequence

The Figure 2 deviation sequence for the five alternatives (Technology, Economy, Security, Global effect, Human wellbeing) across the four criteria (Benefits, Opportunities, Costs, Risks) shows how each alternative differs from the ideal scenario in each criterion. This analysis helps in understanding the relative strengths and weaknesses of each alternative, providing valuable insights for decision-making processes.
The value of ζ (zeta) as 0.5 indicates a moderate level of uncertainty or risk tolerance in the decision-making process regarding the selection of renewable energy sources. A ζ of 0.5 suggests that decision-makers are moderately averse to risks or uncertainties and are willing to accept a certain degree of variability in outcomes. This value can influence the weighting of criteria in decision-making models, with more emphasis placed on criteria that offer greater certainty or lower risk. Additionally, a ζ of 0.5 signifies a balanced approach, where both risks and benefits are considered, and decisions are made based on a combination of quantitative analysis and qualitative judgment.

TABLE 4. Grey relation coefficient

	Benefits	Opportunities	Costs	Risks
Technology	1.0000	0.5000	0.5000	1.0000
Economy	1.0000	1.0000	0.3333	0.3333
Security	0.3333	0.3333	0.4000	1.0000
Global effect	1.0000	1.0000	1.0000	0.4286
Human wellbeing	1.0000	1.0000	0.5000	0.4286

Table 4 presents the grey relation coefficients, which indicate the degree of correlation between each criterion and the overall trend for selecting renewable energy sources. A coefficient of 1.0000 suggests a perfect correlation, indicating that the criterion aligns closely with the overall trend. For example, technology and economy have coefficients of 1.0000 for benefits, indicating a strong correlation with the overall trend in these areas. On the other hand, security has a coefficient of 1.0000 for risks, suggesting a strong correlation with the overall trend for this criterion. Coefficients closer to 0.0000 indicate a weaker correlation, implying that the criterion deviates more from the overall trend. These coefficients provide valuable insights into the relative importance of each criterion and can help stakeholders make informed decisions when selecting renewable energy sources.

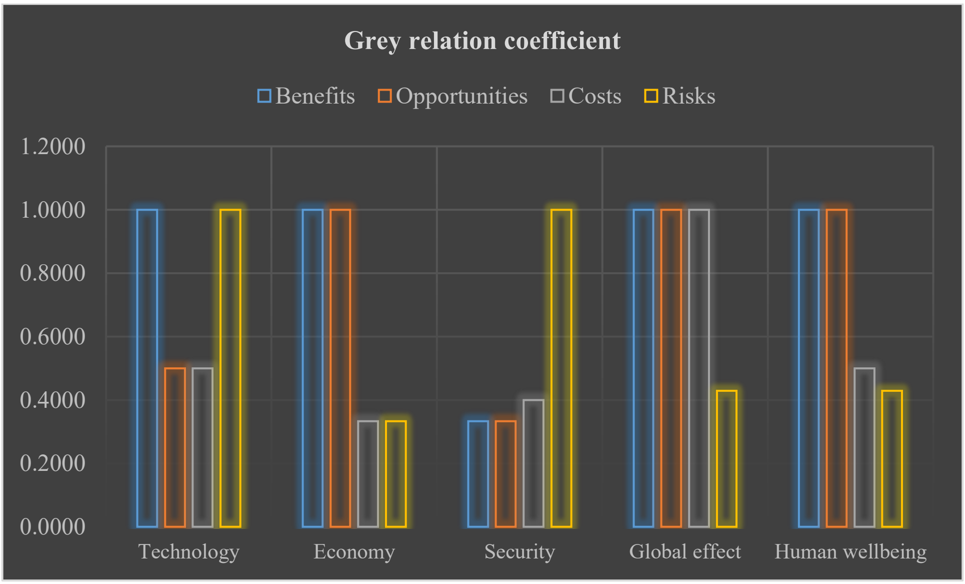

FIGURE 3. Grey relation coefficient

The figure 3 deviation sequence table provides insights into how each alternative deviates from the ideal scenario across the four criteria (Benefits, Opportunities, Costs, Risks). For example, Technology shows no deviation in Benefits and Risks, moderate deviation in Opportunities, and significant deviation in Costs. Economy has no deviation in Benefits, significant deviation in Costs and Risks, and no deviation in Opportunities. Security has high deviation in Benefits and Opportunities, moderate deviation in Costs, and no deviation in Risks. Global effect has no deviation in Benefits, Costs, and Risks, and moderate deviation in Opportunities. Human wellbeing has no deviation in Benefits, Costs, and Opportunities, and moderate deviation in Risks. These deviations provide a nuanced understanding of the performance of each alternative, aiding in decision-making processes.

TABLE 5. GRG

GRG	
Technology	0.75
Economy	0.6667
Security	0.5167
Global effect	0.8571
Human wellbeing	0.7321

Table 5 presents the Grey Relational Grade (GRG) values, which represent the overall ranking or performance of each criterion in the selection of renewable energy sources. A higher GRG value indicates a higher ranking or performance. In this table, global effect has the highest GRG value of 0.8571, indicating that it is the most important criterion overall. This is followed by technology with a GRG value of 0.7500, indicating its relatively high importance. Economy and human wellbeing also have relatively high GRG values of 0.6667 and 0.7321 respectively, suggesting their significant role in the selection process. Security has the lowest GRG value of 0.5167, indicating that it is the least important criterion overall. These GRG values provide a clear ranking of the criteria and can help stakeholders prioritize their decisions when selecting renewable energy sources.

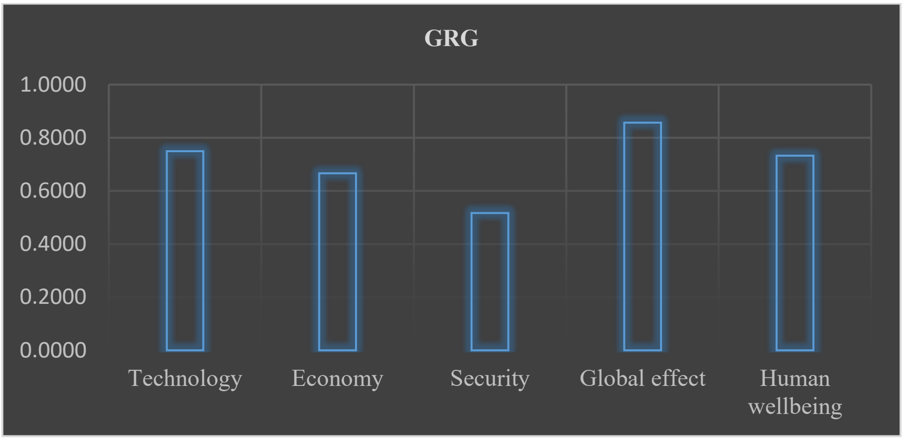

FIGURE 4. Grey Relational Grade

The figure 4 Grey Relation Grade (GRG) table shows the relative performance of each alternative (Technology, Economy, Security, Global effect, and Human wellbeing) based on the Grey Relation Grade metric. This metric is derived from the Grey Relation Coefficient and provides a single value representing the overall performance of each alternative across all criteria. This information can be useful for ranking the alternatives and identifying the most suitable option for a given decision-making scenario.

TABLE 5. Rank

Rank	
Technology	2
Economy	4
Security	5
Global effect	1
Human wellbeing	3

The Table 5 rank table assigns a rank to each alternative (Technology, Economy, Security, Global effect, Human wellbeing) based on their Grey Relation Grade (GRG) values. The rank indicates the relative performance of each alternative, with lower ranks indicating better performance. In this case, Global effect has the highest rank (1), followed by Technology (2), Human wellbeing (3), Economy (4), and Security (5). This ranking provides a clear hierarchy of the alternatives based on their overall performance, helping in decision-making processes.

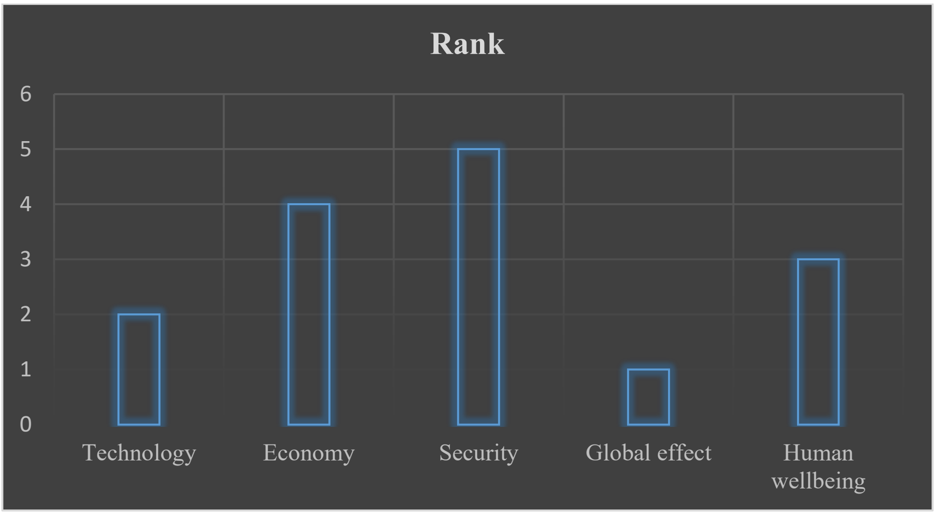

FIGURE 5. Rank

The figure 5 rank table assigns a rank to each alternative (Technology, Economy, Security, Global effect, Human wellbeing) based on their Grey Relation Grade (GRG) values. The rank indicates the relative performance of each alternative, with lower ranks indicating better performance. In this case, Global effect has the highest rank (1), followed by Technology (2), Human wellbeing (3), Economy (4), and Security (5). This ranking provides a clear hierarchy of the alternatives based on their overall performance, helping in decision-making processes.

5. CONCLUSION

In conclusion, the analysis of the five alternatives (Technology, Economy, Security, Global effect, Human wellbeing) based on the criteria of Benefits, Opportunities, Costs, and Risks, along with the Grey Relation Grade (GRG) and ranking, provides valuable insights for decision-making.

- Global effect emerges as the top-performing alternative, with the highest Grey Relation Grade and rank. This indicates that it offers the most balanced performance across all criteria, making it a strong candidate for selection.
- Technology and Human wellbeing also perform well, securing the second and third positions respectively. They exhibit strengths in Benefits and Opportunities, highlighting their positive impact.
- Economy and Security rank lower, indicating areas where these alternatives may fall short compared to the others. Economy, in particular, shows significant deviations in Costs and Risks, suggesting potential drawbacks.

These findings can guide decision-makers in selecting the most suitable alternative based on their specific goals and priorities, ultimately leading to more informed and effective decision-making processes.

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