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ANALYSIS OF CHALLENGES IN ADOPTION OF RENEWABLE ENERGY IN INDIA USING ANALYTICAL HIERARCHICAL PROCESS (AHP)

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ABSTRACT
In India renewable and green energy sources with new technologies have potential to provide solution for rapid increasing demand and growing concern. To emerge as a global leader in the renewable energy sector it is necessary to adopt renewable sources for meeting every demand and tackle the challenges coming in the path of renewable energy generation. India has made significant strides in renewable energy adoption, but numerous challenges hinder large-scale deployment. This research applies the Analytical Hierarchical Process (AHP) to systematically analyze and prioritize these challenges. The study identifies key barriers such as policy uncertainty, financial constraints, infrastructure limitations, technological gaps, and social acceptance issues. By employing AHP, we derive weightages for each category of challenges based on expert inputs. The results provide insights into the most critical barriers that require immediate policy intervention and strategic planning for enhanced renewable energy adoption. The study concludes with recommendations to accelerate India's transition towards a sustainable energy future. The research aims to provide policymakers, investors, and stakeholders with insights into the most pressing issues hindering renewable energy deployment and offers targeted recommendations to accelerate the sector's growth. The research will assist policymakers, investors, and stakeholders with insights into the most pressing issues hindering renewable energy deployment and offers targeted recommendations to accelerate the sector's growth. By identifying and quantifying these challenges, this study contributes to the development of a stable and efficient renewable energy ecosystem in India.

Keywords:
Renewable energy, Challenges, AHP methodology.

I. INTRODUCTION
India is undergoing a transformative shift towards renewable energy as part of its strategy to achieve sustainable development and reduce its dependence on fossil fuels. As the world's third-largest energy consumer, India faces a growing demand for electricity, driven by rapid industrialization, urbanization, and an increasing population. To address this demand while meeting global climate commitments, the government has set ambitious renewable energy targets, aiming to achieve 500 GW of non-fossil fuel capacity by 2030 [1]**.** Various initiatives, including the National Solar Mission, Green Energy Corridor Project, and Renewable Energy Investment Promotion Programs, have accelerated the deployment of solar, wind, hydro, and bio-energy projects. As of 2025, India's installed renewable energy capacity exceeded 175 GW [2], positioning the country as a global leader in clean energy adoption. However, despite these efforts, the large-scale transition to renewable energy is impeded by multiple challenges related to economic, technological, regulatory, and social factors. Addressing these challenges is crucial for ensuring the successful integration of renewable energy into India's energy mix and achieving long-term energy sustainability. Given the complexity of these challenges, a structured and data-driven approach is essential to systematically evaluate and prioritize the barriers to renewable

energy adoption in India. This study employs the Analytical Hierarchical Process (AHP) to assess and rank these challenges based on expert opinions and structured decision-making techniques. The AHP method, developed by [3]**,** is widely used for multi-criteria decision-making**,** allowing for the comparison of various challenges through a hierarchical framework. By applying AHP, this research aims to determine the relative importance of economic, technological, policy, and social challenges and identify the most critical areas that require immediate intervention. This study aims to:

1. Identify and categorize the major challenges hindering renewable energy adoption in India.
2. Apply Analytical Hierarchical Process (AHP) to evaluate and prioritize these challenges based on expert opinions.
3. Provide policy recommendations to address the most critical barriers.

II. LITERATURE REVIEW

India's commitment to renewable energy is evident through its ambitious targets, including achieving 500 GW of non-fossil fuel capacity by 2030 [4]. The growth in renewable capacity in the last 10 years from 35 GW in 2014 to 174.53 GW today is the milestone. Despite significant progress, the nation faces numerous challenges in adopting renewable energy. This literature review examines these challenges, drawing upon recent studies and reports. The main challenges in adoption of renewable and green energy technologies have been identified which is shown in figure

2.1 Economic and Financial Barriers

The high initial capital investment required for renewable energy projects is a significant deterrent. Securing affordable financing is challenging due to perceived risks associated with renewable ventures. [5] Highlights that meeting India's renewable energy targets necessitates approximately USD 189 billion by 2022, with potential shortfalls in both equity and debt financing. Additionally, the renewable energy sector in India faces higher financing costs compared to similar projects in the US or Europe, further hindering deployment.

2.2 Technical and Infrastructure Barriers

Integrating renewable energy into India's existing grid infrastructure presents technical challenges. The intermittent nature of sources like solar and wind necessitates advanced grid management solutions and substantial infrastructure upgrades [6]. Therefore, there is need for significant grid enhancements to accommodate the variability of renewable sources. Furthermore, the current grid infrastructure, designed for conventional power generation, requires modernization to support decentralized renewable inputs.

2.3 Social and Cultural Barriers

Public awareness and acceptance of renewable energy technologies are crucial for their adoption. A significant portion of the Indian populace remains uninformed about the benefits and potential of renewable energy, hindering public support [7]. Educational initiatives and awareness campaigns are essential to bridge this information gap and foster a more receptive environment for renewable energy technologies. Additionally, societal preferences and behavioral patterns significantly influence energy consumption choices, with traditional reliance on conventional energy sources and resistance to change impeding the acceptance of renewable alternatives.

2.4 Policy and Regulatory Barriers

Policy inconsistencies and regulatory hurdles have historically hindered the smooth implementation of renewable energy projects in India. While the government has introduced various incentives and set ambitious targets, challenges persist in terms of policy execution and stability [8]. Delays in approvals, fluctuating tariff structures, and bureaucratic red tape contribute to investor uncertainty and project delays. Authors [7] suggests that a combination of short and long-term policy solutions, such as interest subsidies and accelerated depreciation, could address financing challenges

2.5 Land Acquisition and Environmental Concerns

Securing land for renewable energy projects is challenging due to India's dense population and competing land-use demands. Large-scale projects, such as solar farms, require extensive tracts of

land, leading to potential conflicts with agricultural needs and conservation efforts [9]. For instance, solar parks in Rajasthan have raised concerns over the displacement of grazing lands and ecological impacts. Balancing renewable energy expansion with environmental sustainability and community rights remains a complex issue.

India's renewable energy sector faces a multifaceted array of challenges spanning economic, technical, market, environmental, workforce, policy, and social dimensions. Addressing these barriers requires a holistic approach involving policy reforms, infrastructure development, capacity building, and public engagement. By systematically tackling these challenges, India can enhance its renewable energy adoption and contribute significantly to global sustainability efforts.

III. METHODOLOGY

The AHP methodology compares criteria, or alternatives with respect to a criterion in a natural pair wise mode. The resultant can be used to compare and rank the alternatives and hence, assist the decision maker in making a choice. AHP has the following steps shown in figure 1:

3.1 Step 1- Establishing the hierarchical radical structure

The scale of relative importance, which is a nine-point scale, is shown in table I, and experts are asked to use it to make pair-wise comparisons between barriers and dimensions. An extensive literature review yielded the identification of twenty-five challenges to the widespread adoption of green energy and renewable energy technologies. Expert interviews validated these Challenges and divided them into five dimensions according to their nature. These identified challenges, along with their sub-challenges, have been transformed into a four-level hierarchical process.

Level 1- Goal (Analysis of challenges to adopt the renewable/green energy technologies in Indian context.)

Level 2 - Represent the priority of the identified five dimensions of barriers.

Level 3 -The hierarchy contains of barriers within dimensions.

Level 4 - Contains overall ranking or priorities of barriers renewable / green energy technologies in the Indian context.

3.2 Step 2: Constructing the pair-wise comparison matrix

A set of pair-wise comparison matrices must be constructed in the first step. Comparison matrices have been created from this pair wise comparison of dimensions and barriers. Priority matrices have been determined by using the AHP method to solve these comparison matrices. Dimensions are associated with global priority weights, whereas barriers within a particular dimension are associated with local priority weights.

3.3 Step 3: Calculating the consistency

The maximum Eigen vector or relative weights are used to determine the consistency index (CI) for each order n-matrices matrix in order to guarantee consistency in the element's priority. Equation 2 is used to calculate the consistency ratio (CR) using the CI and random consistency index (RI). The following defines the CI and CR.

Table I: Scale of relative importance

Numerical Rating		Verbal judgement of challenge
1		Equal challenge
3		Moderate challenge
5		Strong challenge
7		Very strong challenge
9		Extreme challenge
2,4,6,8		Intermediate value for challenges

$$CI = (\lambda \text{ max-n}) / (n-1) \qquad (1)$$

The consistency ratio is then calculated using the formula

CR = CI /RI (2)

Where RI varies depending upon the order of matrix. Figure 1 shows the value of the RI for matrices of order (N) 1- 10 obtained by approximating random indices using a sample size of 500.

N	1	2	3	4	5	6	7	8	9	10
R.I.	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Figure 1: Random index

The acceptable CR range varies according to the size of the matrix i.e. 0.05 for a 3×3 matrix, 0.08 for a 4×4 matrix and 0.1 for all larger matrices, n>=5. If the value of CR is less than or equal to that value (0.1), it means that the evaluation in the matrix is acceptable and that the comparative judgment represented in that matrix is consistent in a good way [10]. In contrast, if CR is higher than the acceptable value, the matrix's judgment is inconsistent, necessitating a reevaluation, reconsideration, and enhancement. The reliability of the decision maker in determining the priority of a set of criteria is helped by an acceptable consistency ratio.

IV. CALCULATIONS AND RESULT

By expert evaluations during interactions, matrices are developed, and priorities are synthesized using the AHPAHP framework methodology to address the challenges of adopting renewable/green energy technologies in India. The ranking problem is organized into a four-level hierarchy outlined in the methodology section. This study's GOAL (Level 1) is to examine the obstacles to adopting renewable/green energy technologies in the Indian context.

4.1 Constructing the Hierarchy of Dimensions to Renewable/Green Energy Technologies Adoption: (Level 2)

Five categorized dimensions (Technical, Economical & Financial, Social, Environmental & Geographical, and Political challenges) have been identified for the hierarchy. Table (2) displays the weights assigned by experts to these dimensions and the priority matrix. According to the analytical results in Table (2), the economic and financial challenge (0.280) is identified as the most significant barrier to adopting renewable/green energy technologies, followed by the Technical Challenge (0.275), Social Challenge (0.172), Environmental & Geographical Challenge (0.147), and Political Challenge (0.085).

Table 2: Ranking of dimensions

	Technical	Economical & financial	Social	Environment	Political	Global Weight	Rank
Technical	1.00	2.00	2.00	1.00	2.00	0.275	2
Economical & finance	0.50	1.00	3.00	2.00	3.00	0.280	1
Social	0.50	0.33	1.00	1.00	4.00	0.172	3
Environment	1.00	0.50	1.00	1.00	2.00	0.147	4
Political	5.00	0.33	0.25	0.50	1.00	0.0852	5

4.2 Constructing the Hierarchy of Barriers to Renewable/Green Energy Technologies Adoption (Level 3)

At the third level, experts have rated the barriers within each dimension and checked for hierarchy. The maximum Eigen-value, C.I., and pair-wise comparison matrix of each barrier are presented in Table (3) as follows. Table (3) indicates that within technical challenges, Limited Research & Development Work (1.181) is the most critical barrier in the Technical challenge dimension for adopting renewable/green energy technology, followed by Installation challenge (0.3118), less efficiency (0.2298), less storing capacity (0.141), Lack of smart grid management (0.113), and Quality and reliability of components (0.076). Similarly, dimensions 2 to 5 of barriers/challenges to adopting

renewable/green energy technologies have been ranked accordingly. Table (4) reveals that High land acquisition cost (2.840) is the most significant challenge in the Economical & Financial challenge, followed by High initial cost (0.220), subsidy pricing issue (0.178), High storage cost, import dependence (0.170), and Transmission and distribution loss (0.170). Faith and belief (0.423) are reported as the most significant barriers in the Social Challenge for adopting renewable/green energy technologies, followed by Public perception and consumer awareness (0.305), Resistance to change in energy practices (0.290), and Lack of paying capacity (0.230), as shown in Table (5). From the analytical results in Table 6, Climate and weather dependency (0.255) is identified as the most significant challenge in this dimension, followed by Impact on ecosystem and biodiversity (0.195), Assessment of land allocation (0.166), Land use habitat disruption (0.153), Troubleshooting in real-time (0.126), and Waste management (0.088). From the analytical results in Table (7), Policy and regulatory uncertainty (0.292) is reported as the most significant challenge in adopting renewable/green energy technology, followed by Job creation and infrastructure management (0.282), Bureaucratic hurdles (0.220), and Federal structure & state-level disparities (0.195). The overall rankings of the identified challenges are summarized in table 8

Table 3: Ranking of barriers in "Dimension 1: Technical challenges" to adopt renewable/ green energy technological adoption

	TE1	TE2	TE3	TE4	TE5	TE6	WEIGHT	Rank
TE1	1.00	2.00	3.00	2.00	3.00	3.00	0.3118	2
TE2	0.50	1.00	2.00	2.00	1.00	2.00	0.2298	3
TE3	0.33	0.50	1.00	4.00	2.00	3.00	1.181	1
TE4	0.50	0.50	0.25	1.00	2.00	1.00	0.141	4
TE5	0.33	1.00	0.50	0.50	1.00	2.00	0.113	5
TE6	0.33	0.50	0.33	1.00	0.50	1.00	0.0796	6

Table 4: Ranking of barriers in "DIMENSION-2: Economical & Financial challenges" to adopt renewable/ green energy technologies adoption

	EF1	EF2	EF3	EF4	EF5	Weight	Rank
EF1	1.00	3.00	2.00	1.00	1.00	2.840	1
EF2	0.33	1.00	2.00	2.00	1.00	0.220	2
EF3	0.50	0.50	1.00	1.00	2.00	0.178	3
EF4	1.00	0.50	1.00	1.00	1.00	0.170	4
EF5	1.00	1.00	0.50	1.00	1.00	0.170	4

Table 5: Ranking of barriers in "DIMENSION 3- Social Challenge" to adopt renewable /green energy technologies adoption

	SO1	SO2	SO3	SO4	WEIGHT	Rank
SO1	1.00	2.00	1.00	1.00	0.29	3
SO2	0.50	1.00	1.00	2.00	0.23	4
S03	1.00	1.00	1.00	3.00	0.305	2
S04	1.00	0.50	0.33	1.00	0.423	1

Table 6: Ranking of barriers in "DIMESION -4 Environment and Geographical challenges" to adopt renewable/green energy technologies adoption

	EG1	EG2	EG3	EG4	EG5	EG6	WEIGHT	Rank
EG1	1.00	2.0	2.00	1.0	3.0	2.0	0.255	1
EG2	0.50	1.00	0.5	0.33	2.0	1.0	0.088	6
EG3	0.50	2.00	1.00	0.50	1.0	2.0	0.153	4
EG4	1.0	3.00	2.00	1.0	1.0	0.5	0.195	2
EG5	0.33	2.00	1.00	1.0	1.0	0.2	0.126	5
EG6	0.50	1.00	0.5	2.0	2.0	1	0.166	3

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Table 7: Ranking of barriers in "DIMENSION -5 : Political challenge " to adopt renewable /green energy technologies adoption

	PO1	PO2	PO3	PO4	WEIGHT
PO1	1.00	2.00	1.00	2.00	0.292
PO2	2.00	1.00	0.5	1.00	0.22
PO3	1.00	2.00	1.00	0.33	0.195
PO4	1.00	1.00	3.00	1.00	0.282

*Consistency ratio (C.R.) values are well in acceptable range for matrices shown in table (2-7) which ensure the decision maker's reliability.

Table 8: Overall ranking of challenges

Dimension Of Barriers To Adopt Renewable /Green Energy Technologies	**Global Weight Of Dimension**	**Rank Of Dimension**	**Barriers To Adopt Renewable /Green Energy Technologies**	**Local Weight Of Barriers**	**Overall Weight Of Barriers**	**Overall Weight Of Barriers**
TECHNICAL CHALLENGES	0.324	2nd	1.Installation challenge	0.311	3RD	0.110
			2.Less efficiency	0.229	5TH	0.074
			3.Limited research and development	1.181	2ND	0.382
			4.Less storing capacity	0.141	11TH	0.045
			5.Lack of smart grid management	0.113	13TH	0.036
			6.Quality and reliability of component	0.079	19TH	0.025
ECONOMICAL AND FINANCIAL CHALLENGES	0.7952	1st	1.High land acquisition cost	2.840	1ST	2.258
			2.High initial capital cost	0.220	6TH	0.174
			3.Subsidy and pricing issue	0.178	8TH	0.141
			4.Storage cost and import dependence	0.170	9TH	0.135
			5.Transmission and distribution loss	0.170	9TH	0.135
SOCIAL CHALLENGES	0.727	3rd	1.Resistance to change in energy practices	0.290	8TH	0.210
			2.Lack of paying capacity	0.230	10TH	0.167
			3.Public perception and consumer awareness	0.305	7TH	0.221
			4.Faith and belief	0.423	4TH	0.307

ENVIRONMENT AND GEOGRAPHICAL CHALLENGES	0.0374	4th	1.Climate and weather dependency 2.Waste management 3.Land use and habitat disruption 4.Impact on ecosystem and biodiversity 5.Troubleshooting in real time 6.Assessment of land allocation	0.255 0.088 0.153 0.195 0.126 0.166	12TH 23RD 18TH 14TH 21ST 16TH	0.009 0.003 0.005 0.007 0.004 0.006
POLITICAL CHALLENGES	0.248	5th	1. Policy and regulatory Uncertainty 2. Bureaucratic hurdles 3.Federal structure state level disparities 4.Job creation and infrastructure	0.292 0.220 0.195 0.282	15TH 20TH 22ND 17TH	0.072 0.054 0.048 0.069

V. DISCUSSION AND CONCLUSION

Over the last ten years, renewable energy technologies have garnered significant global interest. These technologies are seen as a promising solution to enhance the living conditions of 8.2 billion people, primarily in rural areas, who lack access to modern energy sources. India is abundant in renewable energy resources, such as solar, wind, biomass, and hydro energy, many of which hold substantial potential for development. These resources could offer commercially viable solutions to fulfill specific energy needs, especially in rural regions, create new job opportunities, and enable local manufacturing of much of the necessary equipment [11]. However, to realize this potential, several obstacles must be addressed, either partially or fully, to boost the market penetration and acceptance of renewable energy technologies. This paper identifies and ranks these barriers using the Analytic Hierarchy Process. A thorough literature review and an idea engineering workshop were conducted to identify and rank these barriers. From an extensive literature review, 25 barriers were identified. Following an extensive brainstorming session, these barriers were categorized into five dimensions. AHP was employed to rank the barriers to adopting renewable/green energy technology. The economic and financial dimension was found to have the highest global weight, while the political dimension had the lowest, ranked from 1st to 5th, respectively. The economic and financial aspect is crucial in today's world, as people are so focused on their own needs that they overlook the depletion of resources and environmental harm.

- "High land acquisition cost" emerged as the top-ranked barrier, while "Storage cost and import dependency" and "Transmission and distribution loss" were the lowest-ranked in that dimension.
- Similarly, "Limited research and development work" was identified as the highest-ranked barrier, with "Quality and reliability" being the least significant in the technical dimension.
- "Faith and belief" received the highest rank, while "Lack of paying capacity" was the lowest in the social dimension.

- "Climate and weather dependency" was reported as the top barrier, with "Waste management" being the lowest in the environmental and geographical dimension.
- "Policy and regulatory uncertainty" was identified as the highest-ranked barrier, while federal structure and state-level disparities were the lowest in the political dimension.

Additionally, a comprehensive ranking of all obstacles has been conducted by assigning global weights. The most significant barriers to the adoption and deployment of renewable/green energy technologies, which are crucial in addressing global climate change, include high land acquisition costs, limited research and development, and installation challenges. Renewable energy technologies have a profoundly positive impact on both the environment and society. This paper could be instrumental in understanding various barriers, and ranking them will aid in their removal, facilitating the more effective and efficient adoption of renewable/green energy technologies in India. The paper introduces a benchmarking framework to assist in making complex decisions regarding the elimination of these challenges. India has the potential to emerge as a global leader in this field, helping managers of renewable energy firms to concentrate on their strengths and implement strategies to address potential weaknesses. The government may need to step in to remove inappropriate, inconsistent, and inadequate policies that favor conventional fuels and technologies, which overlook the social, environmental, and economic benefits of renewable energy. In light of global warming, climate change, and electricity shortages, there is an urgent need for India to plan and implement strategies to increase the share of renewable/green energy in its energy mix. The potential of renewable resources can be harnessed by encouraging innovation and entrepreneurship in this sector. Our research has implications for practitioners, managers, policymakers, and community stakeholders interested in using renewable/green energy technologies to address power issues in developing countries like India. This research also holds significance for scholars who may use the framework and propositions to guide new theoretical and empirical analyses in adopting renewable energy technologies.

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