Renewable Energy in India—Barriers to Wind Energy

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As the world moves toward greater development and growth, it is imperative to appreciate the looming ramifications of environmental degradation and ecological imbalances that are caused by atmospheric carbon emissions. The increased negative effects of fossil fuels on the environment has forced many countries, especially the developed ones, to use renewable energy sources. Recently, renewable energy systems have emerged as a clean and easy-to-maintain alternative to the use of diesel engines for rural electrification. Among them wind energy, biomass energy systems and solar photovoltaic (PV) offer capacity and proven technologies to provide continuous and reliable energy. Wind energy, the fastest developing energy source, is renewable and environment friendly. Systems that convert wind energy to electricity have developed rapidly.

Many clean and energy-efficient technologies contribute to sustainable development and energy security in developing economies. However, in practice these technologies are rarely used. Barriers exist that prevent sustainable, energy-efficient technologies from being more widely utilized and having greater market penetration and diffusion. It is absolutely necessary to overcome these barriers. This chapter aims to identify and rank the barriers to greater diffusion of renewable energy systems particularly wind generation. The barriers identified include lack of knowledge about energy sources, higher investment costs, preferences for grid extension projects, lack of arrangements for long-term operation and maintenance, absence of a certification systems for equipment, and lack of financial instruments for renewable energy entrepreneurs.

Our study identifies and ranks the barriers for the diffusion of wind energy in three wind farm clusters in the southern Indian state of Karnataka based on the perceptions and judgements of the various stake holders. Five main barrier groups are considered and their dimensions are recognized before ranking them based on four different criteria using multicriteria decision making. While all barrier groups

have significant weights, barriers related to policy, organizatinal form and awareness were found to be the primary barriers. This provides a promising domain for regulatory and political policy interventions to enhance the implementation of wind energy. The results provide evidence of how consumers receive wind energy information and make decisions using their analytical capabilities.

INTRODUCTION

At the dawning of the twenty first century, the world experienced growing demand for energy, increased environmental pollution and depleting energy sources. Human society faces two great challenges: the transition towards more sustainable development, and the eradication of poverty. The influential Brundtland report (World Commission on Environment and Development: Our Common Future) defined sustainable development based on the ideal of meeting the needs of the present without compromising the ability of future generations to also meet their needs [1,2]. Eradicating poverty requires the cooperation of industrialized and developing countries. A primary element of eradicating poverty is greater economic development of rural areas in developing countries [3].

Climate change is considered to be among the most serious threats to the world's environmental sustainability. Most scientists agree that the earth's climate is being affected by atmospheric greenhouse gases (GHGs) released by human activities. Since the main economic sector contributing to GHG emissions is the energy sector, transitioning to a more sustainable developmental model must include reducing the use of non-renewable primary energy sources [3]. This calls for increasing the use of renewable energy, which offers other positive consequences including decentralizing electricity generation, reducing external energy dependence, diversifying energy resources and creating employment.

The fundamental characteristic of a sustainable energy system is its ability to deliver required services without exhausting resources. The primary step to designing such a system is to use existing energy resources efficiently and increase the use of renewable energy (RE) resources. Thus, a shift from non-renewable to renewable energy generation technologies is a top priority in efforts to transition to more sustainable energy systems [4]. There exists a direct relationship between development and energy consumption, yet energy production needs to be increased [5]. There is a large potential for renewable energy technologies such as solar PV, wind energy, biomass energy and micro hydro to meet the needs of rural areas in India [6]. Renewables directly contribute to improved quality of life and reduced environmental pollution [7].

Energy has received widespread attention due to the burgeoning demand from the emerging economies, geopolitical factors and excessive volatility in international crude oil prices [8]. India imports 79% of its petroleum. Relying heavily on imported fuels, it is difficult for India to sustain the use of imported fossil fuels [9]. India has been increasingly reliant on imported coal, creating the necessity of considering domestic sources of energy [10]. Regardless, the growth of renewables in India over the last five years has been impressive. RE-based technologies reduce GHG emissions by displacing energy production from the combustion of fossil fuels which emit large quantities of CO_2. Renewable energy reduces India's carbon footprint [10]. However, for India to continue on its path of economic growth, there are issues which must resolved with improved governance [9].

Power Scenario in India

About 1.3 billion people in the world (or about 1 in 5) lacked access to electricity in 2010; the challenge of providing reliable and cost-effective electrical services remains one of the world's major challenges [11]. In 2012, despite a slowing global economy, India's electricity demand continued to rise. India's electricity demand is projected to more than triple between 2005 and 2030. In the recently released national electricity plan (2012), the Central Electricity Authority projected the need for 350-360 GW of total generation capacity by 2022 [12]. Despite major capacity additions over recent decades, power supplies struggle to match demand.

By the beginning of 2015 India had an installed power generation capacity of over 280,000 MW yet many plants are facing shortages of fuel supplies lowering production. About 53 million of the country's homes lack electricity and many industries depend on diesel generators to meet their electricity requirements [13]. Though the government has announced it would improve fuel supplies to natural gas fired plants, it needs to develop plans and compliment them with relief measures since many plants have struggled due to lack of fuel [14]. The sources of installed power in India are shown in Figure 1. Of the total installed capacity of 282,023 MW, 70% is from thermal sources (coal, oil and gas). The rest includes hydro (15%) and other renewables (13%).

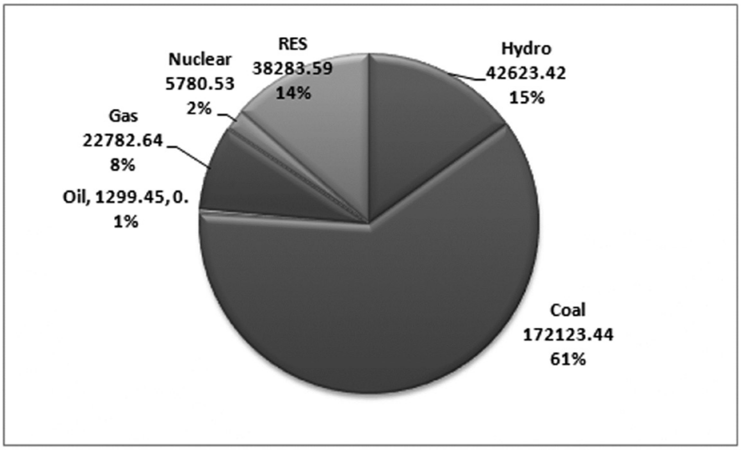

Figure 1. India's 2015 installed power capacity (MW) [15].

Promising continuous electricity supplies to all households by 2019, the government also sees an investment potential of up to 250 billion Rs (approximately 4 billion U.S. dollars) for power generation, transmission, distribution and coal mining. India's total power consumption would double to 2 trillion units by 2019 [15]. Though the majority of investment funds would be provided by the private sector, part of the total would come from the government. The government is moving forward with plans for renewables. It hopes to increase solar power generation by 1,000,000 MW by 2022. It also aims to double the installed capacity of wind generation to more than 40,000 MW by 2019 [16]. Wind energy constitutes a major portion of the installed capacity (excluding rooftop solar). Table 1 shows the potential and installed renewable energy in India.

THE NEED FOR RENEWABLES AND THEIR POWER SECTOR PENETRATION

Industrialization, urbanization, population growth, economic growth, greater per capita consumption of electricity, depletion of coal reserves, increasing imports of coal, crude oil and other energy sources and

Table 1. Potential and installed capacity of renewables in India, November 2015 [13, 15].

Sector	Potential (MW)	Installed (MW)	% Achieved	% of Total Installed
Wind energy	102,788	24,759.3	24.1	64.7
Solar energy	100,000	4,684.7	4.7	12.2
Small hydro power (up to 25 MW)	20,000	4,161.2	20.8	10.9
Biomass and bagasse cogeneration	23,700	4,550.6	19.2	11.9
Waste to energy	3,880	106.6	2.7	0.3
Tidal/wave	Tidal: 8,000-9,000 Wave: 40,000	none	-	-
OTEC	180,000 MW	none	-	-
Geothermal	10,000 MW	none	-	-
Total	270,368	38,261	14.2	100 %

the rising concerns about climate change have placed India in a difficult position. Like many developing countries, India must balance economic development and environmental sustainability. One of the primary challenges for India is to alter its present energy mix which is dominated by coal, including a greater share of cleaner and sustainable energy sources. The total renewable energy potential from various sources in India is 270,368 MW [13]. As of November 2015, the total installed capacity from renewable energy, both grid-interactive and off-grid or captive power, was 38,261 MW. Thus, the untapped market potential for renewable energy in India is 232,107 MW [15].

"...Why not consider RE to be the main occupant of the house and then work out the rest of the system around RE, because RE is the future?"

This remains a key and critical question [17]. For over 100 years, India's conventional fossil-fueled power plants were the core of power generation systems. Those systems had particular engineering and technical characteristics. For decades, operating and governance institutions were created, designed and operated to support systems with those characteristics. But renewables are different. Capturing the benefits of renewables as "the main occupant of the house" will require institutions to be reengineered, policies redefined, power grids and systems retuned and old habits replaced with new ones.

India's RE program is the biggest and most extensive among the developing countries [15]. Though India's renewable resources are abundant, the output of wind and solar photovoltaic is variable and subject to uncertainty. To capture the benefits, India would need to raise more capital and become more comfortable with managing the variability and uncertainty of RE generation [17].

Wind Energy for Power Generation

The use of fossil fuels increases the emission of pollutants including SO_x, NO_x, and carbon monoxide that have detrimental effects on the environment. Hence, the use of alternate energy sources such as wind, solar and hydrogen is gaining importance [18]. Wind power has proven to be a very effective source of energy due to technological richness, infrastructure and relative cost attractiveness. Renewable energy and especially wind energy does not emit atmospheric CO_2—thus it protects us from global warming.

Wind turbine generators (WTGs) have been used for over 100 years to generate electricity [19]. The use of WTGs for renewable energy has become one of the most viable sources of power generation due to its lucrative economics and ecofriendly impacts [20]. Many companies, institutions, organizations and researchers have reported that wind turbines with higher efficiencies are needed to fulfill energy mandates [21]. Though countries lacking natural reservoirs of fossil fuel stocks need to be careful with their use of alternate energy sources, wind turbine technologies have improved during the last three decades [22]. Developments in the technology of WTGs such as power electronics, aerodynamics and mechanical drive train design have made them a more efficient way of producing electrical energy [23,24].

Since 2010, Asia has led the growth of wind energy, as wind energy installations in the region have outstripped both North America and Europe. While China and India have been the main drivers of growth, the projected investments in wind projects in the rest of Asia are expected to exceed $50 billion (U.S.) between 2012 and 2020 [25]. According to the report by the Intergovernmental Panel on Climatic Change (IPCC), wind energy will have a major role in RE electricity generation by 2050 [26]. Its contribution will be about 80% of the world's energy demand.

Progress of Wind Energy in India

Wind energy is increasingly accepted in India as a major complementary energy source for securing a sustainable and clean energy future. [27]. Demonstration wind energy projects were started in 1985. Five wind farms were developed in 1986 with a generation capacity of 3.3 MW. By 1989, India had 10 MW of total installed wind capacity, all from governmental demonstration projects [28]. The first commercial wind power generation project started in Tamil Nadu in 1990. By 1992, many wind turbines were installed in coastal areas of Tamil Nadu, Gujarat, Maharashtra and Orissa. Afterwards, wind power production in India began to grow, mostly by using land-based systems.

Asia's largest and tallest wind turbine was built in India in 2004. Installed wind energy capacity in India increased from 41.3 MW in 1992 to 22,465 MW by the end of 2014 [29]. Among the Indian states, Tamil Nadu experienced the largest growth in wind power energy development and was producing 5,867.2 MW by 2011 and 7,254 MW at the end of 2014 [30]. Other states achieved significant wind power growth by the end of 2014—Maharashtra 4,024.7 MW, Gujarat 3,405.7 MW and Karnataka 2,331.3 MW. India has the wind energy potential to produce 49,130 MW at the 50m height and 102,788 MW at the 80m height above the ground level. By November 2015, India had a total installed wind power generation capacity of 24,759.3 MW [30].

India's renewable energy policies which predominately support on-shore systems, need improvement. European countries, most notably the UK and Germany, have adopted effective offshore policies [24]. Offshore wind power policies should be developed suitable to India's situation.

Wind energy initially generated interest from the scientific perspective rather than for its potential of meeting increasing demand for electricity. It is gaining market share because of its usefulness for decentralized energy generation and distributed generation. The growing gap in electricity demand and supply, greater environmental awareness and the attention to decentralized energy supplies made wind energy important to meeting India's growing demand for energy [31]. In India's 12^{th} plan period from 2012-17, renewable energy capacity was envisaged by the Central Electricity Authority to grow to 32 GW [32]. Nearly 20 GW was to come from wind and 10 GW from solar. India's new government plans to scale up installations to almost 140 GW by 2020—100 GW from solar and 40 GW from wind. This outlook presents new challenges. According to industry estimates, if all barriers to wind farm development were resolved, nearly 40 GW (6-7 GW annually) of wind power installations could be possible by 2020 [33]. These capacity additions necessitate a detailed and critical examination of the barriers faced by renewables.

Karnataka: Renewable Energy Scenario and Rural Electrification

Karnataka has about 30,000 MW of estimated RE potential, making it one of the country's top five RE-rich states. Table 2 shows the sources of installed electrical generation capacity in Karnataka which totals about 15.0 GW with 5.1 GW or 30% from RE sources [34]. The state agency, responsible for RE development under the purview of the energy department is the Karnataka Renewable Energy Development, Ltd. (KREDL). As a facilitator between industry, finance, government and technical experts, KREDL works to increase the deployment of RE in the state.

Table 2. Karnataka: source of installed capacity [34].

Sl. No	Source	Capacity in Nov 2015 (MW)
1.	Hydro	3,773
2.	Thermal	27,20
3.	Diesel	108
4.	CGS	2,169
5.	NCE Source	5,082
6.	IPP	1,200
	Total	15,052

The biggest challenge for utility-scale projects in Karnataka has been project implementation (i.e., progressing from allocation to actual commissioning). Although 60% (19,200.4 MW) of the state's RE potential has been allocated by KREDL, only about 15% (5,082 MW) has been commissioned [35,36]. Table 3 indicates the available and allotted potentials plus the commissioned capacity of the types of renewables in Karnataka.

The allotted capacity of wind energy generation to various groups equaled 13,245 MW as of 2015 with a commissioned capacity of only 2,686 MW (20.3%). A total of 2,623 MW was cancelled and the balance allotted capacity remaining to be commissioned stands at 7,935 MW [34].

The cumulative progress of wind energy installations for major Indian states is shown in Figure 2. The installed capacity for most of the states has doubled over last 6 years.

Electricity Poverty in Rural Areas (Karnataka)

Access to quality electricity services continues to be a major issue in the state of Karnataka, similar to rest of the country. Electricity access is not only essential for households, but is also important basic infrastructure for hospitals, schools and industries. Supported by several years of governmental schemes, electrification in Karnataka has increased between 2001 and 2011 [36]. Almost all (99.95%) of the villages in Karnataka are now electrified (Table 4) as defined by the national rural electrification program, Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY). A village is deemed electrified if public places like schools, Panchayat offices, health facilities, dispensaries, community centers and 10% of all households are electrified. While the village might be grid connected, this status does not guarantee that all households are.

Table 4: Village electrification in Karnataka [32,36].

Total Inhabited Villages as per 2011 census	Villages Electrified as on 03-31-2014		Un-electrified Villages (March 2015)
	Number	Percentage	
27,481	274,684	99.95	13

Even with a high electrification achievement, the 2011 census mentions that 8.6% of the households in Karnataka use kerosene for their lighting, implying that several households lack access to electricity even in officially electrified villages [11,37]. There remains a gap in rural and urban access to electricity, with 96.4% of urban households using electricity as a source of lighting compared to 86.7% in rural areas.

There are a number of issues with electricity access in rural areas. Electrified villages have erratic and unreliable supplies. Secondly, there are remote hamlets, less than 100 households, which are not electrified nor included in the RGGVY plan [41]. Finally, the cost of delivering power from the grid, which includes generation, transmission, and distribution of electricity from a centralized coal thermal power plant is variable.

Kerosene is used in about 12% of the rural households for lighting compared to approximately 3% for urban households [40]. Kerosene combustion emits toxic fumes, causing eye and respiratory ailments and higher associated health costs [32]. Access to electricity improves health and reduces these costs.

Karnataka is home to the ecologically sensitive Western Ghats.

For remote hamlets in these and similar locations, it is technically and economically infeasible to extend the electric grid. Small-scale renewable energy technologies (RETs) can be economically attractive compared to electrical grid extension and provide electricity to these rural areas [32]. Studies suggest that RE resources can meet a substantial portion of the energy demand with currently available technologies [35,36]. This may become a reality only after issues that prevent greater market penetration of RETs are properly addressed. While the government is promoting RETs, renewables have failed to emerge as prominent competitors to conventional energy technologies. This implies that there are barriers to implementing renewable technologies. For RETs to successfully penetrate the power sector markets, the involvement of various stakeholders in the identification of barriers is extremely important [42]. The identification and perceptions of barriers and barrier-removal measures vary across the stakeholders. Unless these are addressed, implemented policies may not function as intended.

IDENTIFYING AND ASSESSING BARRIERS

The need to enact policies supporting renewables is often attributed to a variety of barriers or conditions that prevent greater investments. The barriers create economic, regulatory, or institutional disadvantages for developing renewable energy relative to other forms of energy supply. Barriers include subsidies for conventional forms of energy, high initial capital costs coupled with lack of fuel-price risk assessment, imperfect capital markets, lack of skills or information, poor market acceptance, technology prejudice, financial risks and uncertainties, high transactions costs, and a variety of regulatory and institutional factors [43]. Barriers clearly exist that prevent energy-efficient technologies from being more widely utilized. The major barriers are different for renewable energy technologies. Policy barriers are the key barriers which have given rise to sets of related barriers such as financial and institutional barriers. High investment costs, lack of performance guarantees and lack of access to information are other key barriers [6].

Meyers [44] and UNFCCC [45] outline the following typical types of barriers:

- Institutional—lack of legal and regulatory frameworks, limited institutional capacity and excessive bureaucratic procedures.

- Political—instability, government intervention in domestic markets (for example, subsidies), corruption and lack of civil society.
- Technological—lack of infrastructure, lack of technical standards and institutions for supporting the standards, low technical capabilities of firms and lack of a technology knowledge base.
- Economic—economic instability, inflation, poor macroeconomic conditions and disturbed or non-transparent markets.
- Information—lack of technical data, financial information, and demonstrated capabilities.
- Financial—lack of investment capital and financing instruments.
- Cultural—particular consumer preferences and social biases.
- General—insufficient intellectual property protection and unclear arbitration procedures [46].

Identifying Barriers to Wind Energy Development

Barriers can be defined as factors that inhibit or hinder technology transfer or adoption. This study considers wind energy generation systems (WEGS) as de-centralized renewable energy generation technologies (DCRE). The analysis of barriers and their rankings was performed by completing a comprehensive review of published academic literature and technical reports on energy systems and listing the major barriers noted as hindering the diffusion of renewable energy technologies. The full list of relevant barriers was then refined to a shorter list. Finally, the barriers for implementation of wind energy were categorized into five broad groups. The details of capacity and number of WTGs at the study cluster are provided in Table 5.

Table 5. Details of the wind energy cluster area for study [34].

Capacity of WTGs in kW												Total no. of WTGs	Total capacity MW
250	400	500	800	850	1,250	1,500	1,600	1,650	1,700	2,000	2,100		
Number of WTGs													
14	5	4	178	31	8	10	20	5	29	9	5	318	319.3

The Belgaum district wind farm cluster consists of 318 WTGs with a total installed capacity of 319.3 MW. Their installed capacities range from 250 kW to 2 MW. The district of Belagavi is among the top five districts with the highest potential for wind energy generation.

Our study's objectives were to: 1) identify the barriers to WEGS adoption; 2) specify the major factors that need to be addressed from a policy perspective; and 3) assess the significance of removing the barriers. For the analysis, a questionnaire-based research survey was conducted. Opinions and judgments were collected from wide variety of experts and stakeholders. All respondents were knowledgeable about the power sector and were familiar with RE generation technologies and the barriers hindering their widespread diffusion and adoption. The stakeholders included representatives from households, industrial firms, wind energy developers and policy development. The survey first gauged the respondents' perceptions as to the most significant barriers from a list of major factors (e.g., awareness, information, cost, policy regulations, etc.) and then delved into each factor to determine how it posed obstacles to WEGS.

Information on the state of the wind energy technologies, various policies, and data on factors effecting the penetration of wind energy were collected. The wind energy farms in Belagavi district cluster (Chikkodi, Saundatti, Belagavi and Ramdurg) in the state of Karnataka were selected for the study. Policy makers in the state's energy department, Karnataka State Electricity Board (SEB), KREDL, and energy researchers and practitioners, were consulted to obtain their views on barriers to the diffusion of wind energy technologies. The survey was conducted during the years 2014-2015. The information collected was used for designing the survey's questionnaires. The questionnaires were structured to elicit information on the perceived benefits of WECS, awareness about their costs and benefits, and queries related to barriers such as lack of sufficient information, high initial cost, low electricity tariff, lack of incentives, maintenance problems, and lack of a suitable agency to deal with problems. The respondents were asked to identify the barriers and rank their importance on a given scale. Rankings were normalized and the weighted ranking was determined for each barrier. The barriers to development of RE in India are presented in Table 6. Most are specific to a technology, policy, site or region [4,42,47].

The major barriers vary for the different renewable energy technologies. Policy barriers appear to be key barriers, giving rise to a group of related barriers such as financial and institutional barriers. Other key barriers are high investment costs, lack of guaranteed performance and lack of access to information. Finally, the barriers were grouped into five

Table 6. Classification of energy barriers [42].

Policy and regulatory barriers	Policy framework for RE
	Provision of accelerated depreciation for wind developers
	Regulatory framework for promotion of RE
Institutional barriers	Inter-institutional coordination
	Single window clearance system
Fiscal and financial barriers	Budgetary constraints
	Financing of RE projects
Market-related barriers	Level playing field and market for RE
	Inadequate market prices
	Transmission network
	High equipment costs
	Inputs for RE plants
	Absence of serious developers
Technological barriers	Technology risk
	Absence of minimum standards
	R&D and manufacturing capabilities
	Lack of local technology
Information barriers	Lack of skilled manpower
	Lack of information and awareness

broad categories: 1) policy, political and regulatory barriers (PPRB); 2) technological and geographical barriers (TAGB); 3) economic and financial barriers (EAFB); 4) organizational and institutional barriers (OAIB); and 5) knowledge, information and awareness barriers (KIAB). A brief explanation of these barriers is presented next.

Policy, political and regulatory barriers: There are no sufficient government regulations or incentives to stimulate the adoption of RETs by businesses or industries. Policy support from governmental bodies is lacking in terms of tax benefits, subsidies, depreciation, power distribution, interconnection standards, licensing requirements, environmental and social considerations. Others include: a) lack of explicit national policy at end-use level; b) incomplete transition to cost-based electric tariffs for most residential and some industrial customers; c) poor availability of credit for RETs; and d) lack of modern management skills in energy development agencies. These contribute to many renewable energy technologies in India remaining in the development stage.

Technological and geographical barriers: These include demonstration of project, geographic externalities, wind resource assessment, intermittency or dispersed nature of potential, back up of technology, mismatching load duration curve and grid instability. Wind energy technologies are considered proven and low risk. However, there may be site specific issues which create technical application risks and provide rational reasons for project rejection. Other barriers include: a) lack of standardization in system components resulting from the wide range in design features and technical standards; b) absence of long-term policy instruments that resulted in manufacturing, servicing and maintenance difficulties for wind turbines; c) mismatches between locally manufactured components and imported parts; d) reliability of the overall system and absence of effective servicing and maintenance networks; e) inadequate user-training; and f) lack of co-ordination among research groups, academic institutions and the wind industry.

Economic and financial barriers: These include payback period requirements, financing or funding mechanisms, incentives, discount rates, uncertain economic benefits, market demand, nature of competition and transmission costs. Lack of adequate financial resources has been a chronic problem for establishing wind energy projects. The Indian Renewable Energy Development Agency, Ltd. (IREDA) has a crucial role in supporting the country's wind energy projects. There is a need to create financial institutions who will support wind projects.

Organizational and institutional barriers: These include institutional arrangements through nodal agencies, the importance of the technology, disregarding the options for energy management, small markets, unfair competition, internalization of generating costs, lack of knowledge, lack of infrastructure, and lack of local association activities. Institutional barriers constitute a real constraint, not only to the development of RE sources such as wind but also to their wider dissemination. RE technologies that are relevant to developing countries like India are available. While improvements may be required in individual cases, especially to reduce production costs, the hardware for harnessing wind energy is known and reliable.

Knowledge, information and awareness barriers: These include lack of awareness of concepts, key terms, media exposure, limited databases, availability of training, partial knowledge about the technologies and their benefits and government policies. It is believed that the technologies are not adopted due to lack of information or customer knowledge, or a lack of confidence in obtaining reliable information. India lacks public capacity for disseminating information. There is hardly any consumer knowledge acquisition capability (software or hardware) that is readily available and easily accessible. Given these circumstances, information collection and processing, consumes time and resources which can be difficult for small businesses. Table 7 presents a social, technological, economic and political (STEP) framework for factors that strongly influence India's wind power development [48].

Considering the parameters in Table 7, an analysis of the survey data was performed. The data provided valuable insights into stakeholders' awareness about RETs and barriers to their adoption and diffusion. The opinions of policy analysts about the actions needed to remove the barriers were also revealed [4,42].

Table 7. Framework of factors influencing wind power development [48].

Social	Technical	Economic	Political
NIMBY concerns (Not in my Back Yard)	Stochastic nature of wind power	Externalities not internalized	Political conflict over optimal electricity mix
Level of civic activism	Multi-stakeholder grid management	Other competing alternative technologies	Level of fossil fuel industry opposition
Geographic hurdles	Logistical "bother"	Subsidies to traditional technologies	Diffused alternative energy support
Market information asymmetry	Distance to grid	Insufficient renewable energy subsidies	Energy efficiency initiatives prioritized
Social complacency	Inadequate R&D to improve storage	Long-term fossil fuel purchase commitments	Complacency regarding CO_2 reductions
Electricity price sensitivities, concerns over community impact	Underestimated potential	Market players lack investment incentives; government budget limitations; national advantage in other energy resources	Vertically integrated utility monopoly; weak adjoining grid coordination; lack of R&D support

Overview of AHP Methodology and Barrier Analysis

The barriers for implementing wind energy are broadly categorized into five groups. The ranking of barriers is based on four different criteria namely: 1) barrier removal impact on technology adoption (BRITA); 2) financial difficulty in removal of barriers (FDROB); 3) barrier removal impact on socio-environmental benefits (BRISEB); and 4) barrier removal impact on techno-economic performance (BRITEP). All criteria were measured using Thomas Saaty's nine-point scale as shown in Table 8. The weights for each of the criteria were based on their importance as perceived by the respondents.

The foundation of an analytic hierarchy process (AHP) is a set of axioms which carefully delimits the scope of the problem environment. It is based on a well-defined mathematical structure of consistent matrices and their associated right Eigen vector's ability to generate true or approximate weights [49]. The AHP methodology compares criteria, or

Table 8. Saaty's scale for pair-wise comparison [49].

Numerical Ranking	Definition of Verbal Judgment
1	Equal importance
3	Moderate importance
5	Essential or strong
	importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values (between two adjacent judgments)
1/2, 1/3...1/9	Reciprocals

alternatives with respect to a criterion, in a natural pair-wise mode [49]. The three steps of the AHP methodology are: 1) identifying barriers and structuring a hierarchy prioritization model; 2) constructing a questionnaire and collecting data; and 3) determining the normalized weights for each barrier category and each specific barrier. Opinions from different stakeholders were collected through carefully designed questionnaires and then synthesized and analyzed using the AHP. Consistency checks for the pair-wise comparison matrix were performed by calculating the consistency ratio which should be less than 10 [50].

1. Calculate the Eigen vector or relative weights and λ_{max} for each matrix of order n.
2. Compute the consistency index for each matrix of order n by: $CI = (\lambda_{max} - n)/(n-1)$
3. The consistency ratio is then calculated using the formula: $CR = CI/RI$

Table 12 presents the pair-wise comparisons of the selected four criteria with respect to the objective. Values indicated in Table 12 represent pair wise comparisons in the selected clusters which were obtained by calculating the geometric means of all individual pair-wise comparisons of (XX) participants from the wind farm clusters. It also shows the priority vector (weights of each criterion) in the clusters computed by a process of averaging over the normalized columns as per the AHP methodology. The priority column in Table 9 is obtained by dividing each matrix element by the sum of respective column elements (normalization of column) and then by calculating the arithmetic mean of each row.

Table 9. AHP-pair-wise comparison of criteria.

CRITERIA	FDROB	BRITA	BRISEB	BRITEP	PRIORITY
FDROB	1.00	1.25	0.80	0.22	0.132
BRITA	0.80	1.00	0.40	0.18	0.114
BRISEB	1.25	2.50	1.00	0.33	0.163
BRITEP	4.55	5.56	3.00	1.00	0.592

From Table 9 it can be inferred that the various stakeholders give maximum priority to BRITEP and BRISEB. It is obvious that the stake holders insist on the advancement of the technical and economic performance of wind farms. Improving socio-environmental benefits and outcomes after the technical benefits is also important. FDROB scores a reasonable priority ahead BRITA which has the least weight. Considering a very low weight for BRITA, it is ascertained that the stakeholders are not overly concerned about barrier removal impact on technology adoption and are more concerned about improving the technical and economic performance. Improvements in technical and economic performance benefit wind farm development.

Next the relative weights for individual barrier groups under each of the four criteria were obtained. For this purpose, the pair-wise comparisons of five barriers with respect to each of the four criteria were performed using AHP. The corresponding results of AHP analysis of barriers under the criteria (FDROB) are provided in Table 10. Similar to the previous step, column normalization followed by computing the arithmetic mean of each row yields the respective weights of the barriers under a particular criterion. This above mentioned procedure was extended to the remaining criteria to obtain the relative weights.

Table 10. Pair-wise comparision of barriers with respect to criteria.

Barrier removal impact on Technology Adoption (BRITA)						
Barrier	**EAFB**	**PPRB**	**OAIB**	**KAIB**	**TAGB**	**FRW**
EAFB	1.00	1.59	5.26	1.16	1.35	0.293
PPRB	0.63	1.00	4.55	2.04	0.96	0.255
OAIB	0.19	0.22	1.00	0.65	0.51	0.076
KAIB	0.86	0.49	1.55	1.00	2.44	0.210
TAGB	0.74	1.04	1.96	0.41	1.00	0.166
CR = 7.63%						

Table 11 presents the values for the weight of the criteria under each barrier, the priorities of the criteria, and the final composite weights for each barrier group based on the given rankings. To determine the final composite weight for each barrier group in the clusters, these local weights are multiplied by criteria priority and then aggregated. From these results it can be opined that PPRB leads OAIB and TAGB with a marginal difference followed by EAFB and KAIB ranked last.

In Table 11 it can be observed that, given the criterion FDROB, the PPRB barrier group has the maximum priority. This needs to be addressed for implementation of WTGs. In the same critrion, PPRB is followed by TAGB which is the second most important barrier. Again both EAFB and AIOB obtained lower values. The lowest ranking barrier group in this category was KAIB.

Table 11. Composite weight and barrier ranking in wind farm cluster.

Barrier Group	Criterion Weights				Composite Weight - Final	Rank
	FDROB	BRITA	BRISEB	BRITEP		
EAFB	0.120	0.293	0.112	0.062		4.00
PPRB	0.530	0.255	0.497	0.466	0.132	1.00
OAIB	0.096	0.076	0.213	0.254	0.114	2.00
KAIB	0.027	0.210	0.045	0.061	0.163	5.00
TAGB	0.227	0.166	0.133	0.156	0.592	3.00

Similarly, given the weights of barriers related to criterion BRITA, the wind farm has ascribed a maximum value to EAFB. PPRB and KAIB obtained values that are close to each other. The barrier group of OAIB had less importance with respect to the criterion followed by TAGB. Considering BRISEB and BRITEP, the wind farm clusters judged PPRB the highest, ahead of all other barriers. OAIB and TAGB were second and third with respect to both criterion BRISEB and BRITEP with KAIB obtaining the least weight.

Barriers and Ranking by Weighted Average Score

Each respondent from the different sectors was given a detailed examination of the context of the issues that are involved together with the list of barriers. They were asked to indicate the importance of each barrier to them on a five-point scale (Table 12). The '1' on the scale indicated 'extremely important' (indicating maximum impact of removing a barrier on adoption of technology), 3 on the scale indicated 'important' (average), and '5' indicated the 'least important' (least impact of removing a barrier on adoption of technology) [4].

Table 12. The five-point scale for ranking [4].

Scale	1	2	3	4	5
Importance of barrier	Extremely important	Moderately important	Important	Less important	Least important

The ability to make qualitative distinctions is represented by attributes, such as equal, weak and strong or otherwise stated, rejection, indifference and acceptance. Each of these can be subdivided into low, medium and high indicating nine scales of distinction. The weighted average score for each barrier was determined by using normalized weights. The barriers were ranked according to their weighted average scores. These final ranks indicate the relative importance of the barriers from the stakeholders' perspective. The weights given to the scale of importance (1-5) of the stakeholders were 5/15 points (to importance 1), 4/15, 3/15, 2/15 and 1/15 (to importance 5), the total of weights being 1. A negative response was assigned a 0 weight, indicating that the barrier is not at all important to the respondent. These weights were multiplied by the number of responses for each barrier and the weighted averages were calculated. The barriers were then ranked based on these weighted averages [4,42].

Barrier Rankings: Wind Energy Developers

Information-related issues emerged in the category of most important barriers. Economic barriers were of major concern to the wind energy developers which indicated difficulties in accessing financing. The regulatory barriers resulted in problems with land acquisition and obtaining clearances whereas the lack of infrastructure added to the cost. Ever changing governmental policies created uncertainty and increases in associated costs. In addition, economic barriers were perceived to result from the high cost of development, inadequate incentives, and delays in receiving funds from governmental agencies. Changing depreciation methodologies were also seen as a factor causing increased wind power costs. Also, the prices paid by utilities for power was quite low. Failure of the existing institutions to deliver the results needed is evident from this analysis. Various organizations including governmental agencies were considered to be insensitive to the needs of developers.

Table 13. Ranking of barriers.

Barrier	Ranks and responses (number)					Weighted average
	1	2	3	4	5	
Difficulty in getting clearances	2	1	1	2	3	0.133
Poor Infrastructure facilities	3	2	3	2	1	0.206
Inadequate incentives	3	2	2	2	1	0.189
Hurdles in land acquisition	4	4	3	2	0	0.272
Inconsistency in government policies	0	1	1	2	2	0.072
Long delay in receipt of payments	0	1	1	1	2	0.061
Miscellaneous and others (local)	0	1	1	1	3	0.067

Table 14. Ranking of barriers groups.

Barrier	Ranks and responses (number)					Weighted Average
	1	2	3	4	5	
Economic and financial barriers	1	2	0	1	4	0.106
Policy, political and regulatory barriers	6	4	5	3	1	0.378
Organizational and institutional barriers	2	4	5	1	2	0.250
Knowledge, information and awareness barriers	1	0	1	3	2	0.089
Technological and geographical barriers	2	2	1	4	3	0.178
	12	12	12	12	12	1.000

Overall Barrier Ranking in Wind Farm Clusters

For the wind farms, policy, political and regulatory barriers (PPRB) are ranked first followed by organizational and institutional barriers (OAIB), technological and geographical barriers (TAGB), economic and financial barriers (EAFB), and knowledge awareness and information barriers (KAIB) in that order. It is clearly established that PPRB is the single greatest barrier group affecting wind energy technology (WET) implementation. This ranking identifies the following outcomes:

- No barrier group is negligible. Their weights support the assumption of our study that all considered barrier groups are relevant and significant in the wind farm clusters.
- PPRB and OAIB are the most important brriers that need to be considered to enhance the implementation of wind energy.
- The least weight for KAIB indicates that there is considerable awareness and information about WETs. These concerns are not significantly hindering WET implementation.
- A relatively low weight for EAFB underscores the point that investors are ready and willing to invest in WET provided the appropriate policies and institutional networks are provided.

The implementation of wind energy initiatives must address the policy and regulatory aspects of wind energy power plants. There are multiple reasons for the highest ranking of the PPRB barrier group in the wind energy clusters. First, most stake holders feel that obtaining approvals from government agencies or organizations is very difficult. Secondly, requiring that developers sell their electricity to the State Electricity Board (SEB) through power purchasing agreements (PPAs) is a major policy hurdle. Recently, government orders for allotment and enhancement were issued subject to this condition. This condition should be removed for captive or third party sales, since it should be the investor's decision as whether or not to sell power to the SEB or to opt for wheeling and banking. Thirdly, policies for fixing the deadlines for project completion, capacity enhancements, and repowering of wind farms are needed for effective implementation of WETs.

Apart from PPRB, addressing the OAIB and the TAGB are also important. It is generally felt that any policy and regulatory initiatives will not be able to effectively address WET implementation unless the critical problems of technology, geography, finance, institutional arrangements and organizational issues are addressed on a prioritized basis. EAFB is fourth in the ranking, indicating that stake holders do not rate this barrier highly. In other words, investors are wiling to invest in wind technology provided other hurdles are cleared. The ranking also shows the awareness and information barrier is not posing a serious challenge in WET implementation.

SUMMARY OF RESULTS

The objective of this study was to prioritize the five barrier groups based on all four criteria using the AHP. An initial ranking of barriers based on each individual criterion indicates the need for a multi criterion approach. Based on the 'impact of barrier removal' alone, EAFB has the highest ranking for wind farms while PPRB and KAIB ranked second and third for wind energy implementation. Further, OAIB was the lowest ranked barrier. For 'financial difficulty in barrier removal of barrier' as a criterion for ranking, the PPRB received the top ranking, while TAGB and EAFB ranked second and third rank for wind energy implementation. Further, OAIB ranked fourth while KAIB ranked last. Considering the potential of 'barrier removal impact on techno-economic performance' PPRB again tops the ranking. It was followed by OAIB and TAGB, while both EAFB and KAIB were equally strong and shared the lowest ranking. OAIB again ranked second. With the slight difference between TAGB and EAFB, the former ranked third while the later ranked fourth. KAIB had the lowest ranking as a barrier.

This approach was based on individual criterion while ignoring others. It is inadequate for prioritizing the barriers since it does not provide a holistic view. For example, the barrier KAIB, which obtained the last rank using three criteria, has considerable strength in terms of the impact of barrier removal on adoption of technology and must not be ignored. Therefore, prioritizing the barriers by considering the effects of all the influencing factors simultaneously is improtrant. It is for this reason that a multicriteria decision tool (the AHP) was adopted in this study. The results of the weighed averages present a similar scenario.

Policy recommendations: The state of Karnataka is viewed as the key enabler for promoting renewable and energy-efficient technologies. There is an urgent need for a public policy to invest in these solutions.

A transition from fossil-based conventional fuels to renewables-based energy systems would have to rely largely on successful development and diffusion of these technologies. The RETs could become increasingly competitive through cost reductions resulting from technological and organizational development. Different technologies vary widely in their technological maturity, commercial status and integration aspects. Policies aimed at accelerating renewable energy must be sensitive to these differences.

Key issues related to faster diffusion of RETs include a strong need to improve the reliability of technologies and introduce consumer-desired features (in terms of services and financial commitments) in the designs and sales packages. Including renewable energy strategies in development programs will promote decentralized applications. Renewable energy strategies should be included in the energy sector regulatory framework. Governmental policies should encourage more private participation and industry collaboration in research and development (R&D) for rapid commercialization of RETs. Most renewables are not yet competitive with fossil technologies, especially for power generation purposes. Further commercialization will demand intense R&D efforts. Renewables need to gain the confidence of developers, customers, planners and financiers.

The lack of knowledge about the technologies and their applications is the most important barrier to the use of renewables. The absence of a reliable offer for renewable energy equipment and the frequent lack of arrangements for the long-term management and operation of renewable energy projects are barriers to the penetration of renewables in rural markets. Both barriers limit the long-term sustainability of renewable energy projects.

- Two basic measures have been proposed to guarantee the long-term sustainability of renewable energy projects: 1) training for operation and maintenance (O&M) technicians; and 2) standardization and certification of renewable energy equipment to warrant its quality.
- A solid management model is the key for the long-term sustainability of rural electrification projects. The participation of local people in O&M tasks, and a tariff system that covers the costs associated to those tasks, are basic requirements for a sound management model.
- Crucial elements for the sustainability of rural electrification projects are the quality, reliability, and warranty of the equipment installed,

and the service provided by the equipment supplier. An assessment of the local characteristics of the project—including local energy needs, available energy resources, capacity and willingness to pay—is important for the success of any rural electrification project.

CONCLUSIONS

The enormous potential of renewable energy resources is sufficient to meet the world's demand for energy many times over. Renewables can reduce local and global atmospheric emissions, enhance diversity in energy supply markets and have potential to contribute to long-term sustainable energy supplies. Many countries including India have established national targets for the long-term development of renewables and are integrating clean energy into national regulatory frameworks. Communities, individual consumers and investors are also actively contributing to and participating in renewable energy development plans. India, despite being a pioneer in the Asian region in formulating and implementing innovative policies for promoting renewable energy technologies, has experienced only slow to moderate growth in the use of alternative technologies. This is mainly due to the presence of variable barriers to the promotion of renewable technologies. Among them, policy-related barriers appear to be the major ones, particularly the financial and institutional barriers. Therefore, an emphasis on supportive policy initiatives by the government is essential for overcoming barriers to the promotion of renewables in India.

RETs have potential to provide commercially attractive options to meet specific needs for energy services, particularly in rural areas. They create new employment opportunities, and offer opportunities to manufacture equipment locally. To achieve this goal, a number of barriers must be overcome to increase the market penetration of renewables. A formal survey was used to analyze the major barriers to wider adoption of wind energy technologies. The results of the expert survey can be summarized as follows: the dominant barriers to wider adoption of wind power are financial or infrastructure hurdles, institutional constraints and deficiencies in government policy.

Currently, about 9.6% of every 100,000 households in rural Karnataka lack access to electricity even though 99.5% of villages are electrified. Several households already in electrified villages are not grid connected and those that have grid access are plagued with poor electrical quality and supply availability. The state needs to encourage the growth of small-scale rural electrification projects by making clear, comprehensive guidelines for the market-based implementation of RE projects in un-electrified and under-served areas.

India's renewable resources are abundant, but the output of wind and solar photovoltaic is variable, and in the case of wind subject to uncertainty. To capture the benefits, India would need to raise the necessary capital, and become comfortable with managing the variability and uncertainty of renewable energy generation. To help policymakers identify the new approaches, a stakeholder-driven analysis of the barriers to the rapid deployment of RE was performed. The resulting process and its findings have relevance. In the present scenario, the government of India has enhanced its aspirations multifold—amending them from 20 GW of solar power (by 2022) to 100 GW (by 2019) and adding 15 GW of wind power (during 2012-17) to an additional 40 GW (by 2019).

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