Modeling wind energy development barriers: implications for promoting green energy sector

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\textbf{ABSTRACT}
Since a variety of barriers pose challenges to the Indian wind energy sector, the extent to which these barriers hamper this sector and the alternative solutions are largely unknown. We identify several barriers using existing literature, and then using the modified Delphi approach, refine 25 barriers and classify them into five significant dimensions. Later, the Analytical Hierarchical Process determined the ranking of barriers using pairwise comparison matrices. The Grey Technique for Order Preference by Similarity to Ideal Solution method ranked alternative solutions to these barriers. Results indicate that “financial barrier” is the most important barrier among all dimensions, while “limited government subsidy” is most influential among all sub-bars. “Availability of adequate funds” is the best alternative to overcome these barriers. Finally, a sensitivity analysis is performed to validate the study findings. The study findings may assist practitioners and policymakers in boosting the current sluggish growth of the Indian wind sector.

\textbf{KEYWORDS}
Analytical hierarchical process; barriers; grey technique for order preference by similarity to ideal solution method; India; modified Delphi method; wind energy development

1. Introduction

Energy demand has risen exponentially due to the worldwide economic growth initiatives. A constant supply of energy is needed for all sectors of life, including education, agriculture, transport, mining, and health care (Guler et al. 2021). However, it is always challenging to discover reliable and innovative ways of energy generation. Out of various renewable sources, wind energy not only has the capacity to upgrade the energy structure but can also reduce carbon footprints and promote sustainable development (Probst et al. 2020). During the last decade, the global installed wind capacity has grown exponentially. According to the International Renewable Energy Association (IRENA), the global wind power capacity has reached 733,276 Megawatts (GW) at the end of 2020. A significant amount of wind power, i.e., 111,027 MW, was added during 2019, witnessing the massive development of this sector (IRENA 2021). Ten countries retain 83.4% share of wind energy worldwide. China, for example, installed 281,993 MW of wind energy capacity, followed by the United States with 117,744 MW, Germany with 62,184 MW, India with 38,559 MW, Spain with 27,089 MW, the United Kingdom with 24,665 MW, Italy with 17,382 MW, France with 17,198 MW, Canada with 13,577 MW, and Denmark with 10,839 MW, respectively (IRENA 2021). Figure 1 depicts the worldwide total installed
wind power capacity, whereas Table 1 reports the total installed wind power capacity among the top ten nations worldwide (IRENA 2021).

As a developing country, India realizes most of its power requirements from fossil fuels. Such massive reliance on these sources would lead India to an unwanted state of fossil fuels scarcity in the future. To handle this situation and minimize the reliance on fossil fuels, the Indian government is developing wind power industry (Rani et al. 2020). Several plans and policies for maximizing the share of wind energy have been put forward in this respect (Elavarasan et al. 2021). According to the Ministry of New and Renewable Energy (MNRE), a wind power potential of 302 Gigawatts (GW) exists in the seven windy states of India. Gujarat leads other states with a total installed wind power capacity of 84,431 Megawatts (MW). Karnataka ranks second with 55,857 MW installed capacity. Maharashtra (45,394 MW) ranks third, while Andhra Pradesh (44,229 MW) ranks fourth, respectively (MOSPI 2020). Due to government initiatives, developers have shown great interest in wind power development schemes, and new wind farms have been set up at different localities in the country (Chandra et al. 2019). Some largest Indian wind farms are reported in Table 2. The country has made impressive use of wind resources, which is evident from the recent wind power installations. The country currently has the fourth-highest wind installed capacity globally, with a total installed capacity of 38,559 MW (IRENA 2021). The installed wind power capacity and percentage share among different Indian states have been reported in Table 3.

Despite having vast wind resources, a number of barriers are preventing the smooth development of the wind power sector (Manju and Sagar 2017). There would be no significant improvements in the wind sector until these barriers are well identified and adequately addressed. Therefore, classifying, evaluating, and ranking such barriers as per their significance is pivotal to develop customized solutions. In this regard, researchers have identified barriers related to wind energy development and acceptance worldwide. For instance, Caporale et al. (2020) performed a study to identify the major barriers to hindering the social acceptance of wind energy in the European context. The authors employed the qualitative (focus Group), and quantitative (optimized-AHP and Monte Carlo simulation) approaches to categorize barriers. The study findings suggest a critical attitude due to misinformation and a lack of transparency of governmental institutions. Moreover, the density of turbines, dismantling process, and impacts on landscape and ecosystems were identified as the major concerns. Zhou and Yang (2020) investigated barriers related to risk management in distributed wind energy implementation by employing the AHP approach. The analysis revealed 21 barriers in 4 main
Table 1. Total installed wind power capacity among top ten economies (MW). Data source: [IRENA 2021].

| Year | China | USA | Germany | India | Spain | UK | Italy | France | Canada | Denmark | Top ten countries | World | Proportion of top ten economies (%) |
|------|-------|-----|---------|-------|-------|----|-------|--------|--------|---------|--------------------|-------|-------------------------------|
| 2011 | 46,355| 45,676| 28,712  | 16,179| 6,596 | 6,758| 1,426 | 5,265  | 6,918  | 185,414 | 220,019            | 84.3  |
| 2012 | 61,597| 59,075| 30,979  | 17,300| 9,030 | 7,607| 1,894 | 6,201  | 8,102  | 224,574 | 266,908            | 84.1  |
| 2013 | 76,731| 59,973| 33,477  | 18,420| 11,282| 8,156| 2,202 | 7,801  | 8,542  | 249,542 | 299,919            | 83.2  |
| 2014 | 96,819| 64,232| 38,614  | 22,465| 13,074| 9,201| 4,888 | 9,694  | 8,683  | 290,595 | 349,300            | 83.2  |
| 2015 | 131,048| 72,573| 44,580  | 25,088| 14,306| 10,298| 7,633 | 11,214 | 9,137  | 348,820 | 416,248            | 83.8  |
| 2016 | 148,517| 81,286| 49,435  | 28,700| 16,126| 11,567| 10,129| 11,973 | 9,384  | 390,107 | 466,864            | 83.6  |
| 2017 | 164,374| 87,597| 55,580  | 32,848| 19,585| 13,499| 12,304| 12,403 | 9,737  | 431,051 | 514,374            | 83.8  |
| 2018 | 184,665| 94,417| 58,721  | 35,288| 23,124| 19,585| 13,499| 12,304| 12,403 | 431,051 | 514,374            | 83.8  |
| 2019 | 209,582| 103,571| 60,721  | 37,505| 25,831| 24,095| 16,427| 15,438| 13,413| 517,014 | 622,249            | 83.1  |
| 2020 | 281,993| 117,744| 62,184  | 38,559| 27,089| 24,665| 17,382| 17,198| 13,577| 611,230 | 733,276            | 83.4  |
categories. The results disclose that political, economic, and social risks significantly affect distributed wind power investment, while technical risks tend to have less effect. Diógenes et al. (2020) performed a systematic review to identify onshore wind energy implementation barriers in 159 countries. The analysis specified 31 barriers to wind energy implementation in these countries.

Some scholars have also scrutinized wind energy development barriers in the Indian context. For instance, Kulkarni and Anil (2018) identified and ranked barriers for the diffusion of wind energy in three wind farm clusters in the southern Indian state of Karnataka. The authors identified five main barrier groups AHP approach. Barriers related to policy, organizational form, and awareness were the most significant ones compared to technological and economic barriers. Govindan and Shankar (2016) examined the essential barriers to off-shore wind energy using the AHP method. The study concluded that among the 12 common barriers, “high capital cost” is the most important barrier involved in implementing offshore wind energy farms. Other barriers include wind characterization, physical constraints related to seabed usage, ineffective policies, lack of transmission and infrastructure, lack of knowledge and experience, lack of involvement of stakeholders, lack of technological learning, unavailability of local expertise, lack of ecosystem R&D, lack of incentives, and environmental clearance problems. Similarly, Kar and Sharma (2015) using an extensive literature review discusses major barriers to Indian wind energy development. The findings categorized these barriers under five major dimensions.

The aforementioned research made excellent strides in identifying barriers to wind energy development. Nonetheless, those studies lacked the following areas: First, they remained confined to identifying barriers to wind energy development without prioritizing their relative importance. Second, the identified barriers could vary, depending on the country’s economic, social, political, and technological situations. In this context, studies investigating and prioritizing those barriers in the Indian context are limited. Third, no study has been known to provide prioritization-guided policy alternative solutions to wind energy development barriers. These research gaps need immediate examination in order to address the slow pace of wind energy growth. More specifically, this study aims to respond to the below-mentioned questions.

### Table 2. Largest wind farms of India (Irfan et al. 2019).

| Sr. No. | States          | Wind farm            | Capacity (MW) |
|---------|-----------------|----------------------|---------------|
| 1       | Tamil Nadu      | Muppandal wind farm  | 1,500         |
| 2       | Rajasthan       | Jaisalmer wind farm  | 1,064         |
| 3       | Maharashtra     | Brahmanvel wind farm | 528           |
| 4       | Maharashtra     | Dhalgaon wind farm   | 278           |
| 5       | Maharashtra     | Vankusawade wind farm| 259           |
| 6       | Maharashtra     | Vaspet wind farm     | 144           |
| 7       | Andhra Pradesh  | Beluguppa wind farm  | 100.8         |
| 8       | Madhya Pradesh  | Mamatkheeda wind farm| 100.5         |
| 9       | Andhra Pradesh  | Anantapur wind farm  | 100           |
| 10      | Odisha          | Damanjodi wind farm  | 99            |

### Table 3. Comparison of installed wind power capacity among Indian states. Data source: (MNRE 2021).

| Sr. No | States          | Installed wind power capacity (MW) | Share (%) |
|--------|-----------------|------------------------------------|-----------|
| 1      | Andhra Pradesh  | 4,092                              | 10.59     |
| 2      | Gujarat         | 8,192                              | 21.21     |
| 3      | Karnataka       | 4,868                              | 12.60     |
| 4      | Kerala          | 62.5                               | 0.16      |
| 5      | Madhya Pradesh  | 2519                               | 6.52      |
| 6      | Maharashtra     | 5,000                              | 12.95     |
| 7      | Rajasthan       | 4,326                              | 11.20     |
| 8      | Tamil Nadu      | 9,428                              | 24.41     |
| 9      | Telangana       | 128                                | 0.33      |
| 10     | Others          | 8.5                                | 0.02      |
| Total  |                 | 38,624                             | 100       |
(i) What are the main barriers to the growth of Indian wind energy?
(ii) How can we rank those barriers that have value for all stakeholders?
(iii) Are there any alternative strategies for incapacitating such barriers to accelerate wind energy development?

The current work provides threefold contributions to the existing pool of knowledge by addressing these research questions. Firstly, contrary to previous studies, we identified those barriers by performing a comprehensive literature review and then refined those barriers using experts’ opinions by employing the modified Delphi method. Secondly, we calculated weights to rank those barriers utilizing the AHP approach. Finally, we prioritized the alternatives to overcoming those barriers using the Grey Technique for Order Preference by Similarity to Ideal Solution (G-TOPSIS) method. This is the first study to identify and order barriers while prioritizing alternatives to wind energy development employing modified Delphi, AHP, and G-TOPSIS methods in the Indian context. According to the best of the authors’ knowledge, no study has been conducted in this context. Identifying barriers and prioritizing alternatives would demonstrate a clear insight into which barriers should be addressed promptly to speed up wind energy development.

The remaining research is performed in the following context: Section 2 discusses the literature review. Section 3 elaborates the materials and methods used in the study. Section 4 provides study results. Section 5 provides a detailed discussion of the study findings. Section 6 provides conclusions, and section 7 enlists policy implications.

2. Literature review

Wind energy has captured the attention of numerous countries throughout the world over the last few decades. Governments promoted and disseminated wind technology with the assistance of different institutions and established considerable wind power facilities (Ryberg et al. 2019). Nonetheless, domestic wind technology implementation appears to be less effective in some South Asian countries, including Pakistan, Bangladesh, Nepal, Bhutan, Maldives, Sri Lanka, and Afghanistan, while being more effective in other Asian and European countries, where distributed wind energy systems are continuously growing. A variety of action plans were identified as major driving forces contributing to the success of wind energy programs. These driving forces include: favorable government policies, enough financial support (Ru et al. 2012), improved technological innovation through product research and development, personnel capability building, and an effective quality assurance mechanism (Mahdy and Bahaj 2018; Razzaq et al. 2021).

Even successful wind energy programs and initiatives have never been met without encountering barriers. As a result, it is of utmost importance to conduct a thorough investigation of these barriers to devise solutions and increase the share of wind energy. Several case studies, conducted at the continental level in Africa (Ouedraogo 2019), Europe (Maleki-Dizaji et al. 2020), and Asia (Burke et al. 2019; Duc Luong 2015; Schumacher and Yang 2018; Sharma and Sinha 2019; Thakur and Mithulananthan 2010), scrutinized barriers to wind energy dissemination programs. Table 4 summarizes the most often reported barriers to wind power schemes.

The critical financial barriers include limited government subsidies, high initial cost, high duties on importing foreign equipment, limited share of foreign investment, absence of financial framework, debt and equity problems, and competition among different energy sources. Technological barriers include inefficient domestic technology, lack of production facilities, reliance on foreign economies for key equipment, lack of R&D activities, lack of professional workforce, inefficient wind turbine technology, and inappropriate forecasting and scheduling techniques. Infrastructure barriers comprise land acquisition complexity, inaccessibility to railway and highways, transmission and distribution (T&D) losses, old grid configuration, the absence of institutional framework, inadequate grid infrastructure, and undeveloped market infrastructure. Policy & regulatory barriers entail the lack of a comprehensive wind power policy, unbalanced feed-in-tariff (FIT), political instability, lack of
Table 4. List of barriers influencing wind energy development.

| Barriers | References |
|----------|------------|
| Financial barriers (FNL) | (Burke et al. 2019) |
| Limited government subsidies | (Diógenes et al. 2020) |
| High initial cost | (Gebreslassie 2021; Raina and Sinha 2019) |
| High duties on importing foreign equipment | (Keeley and Matsumoto 2018) |
| Limited share of foreign investment | (Fast et al. 2016; Lolla, Roy, and Chowdhury 2015) |
| Absence of financial framework | (Agarwal, Verma, and Gaurh 2016; Sharma and Sinha 2019; Welch and Venkateswaran 2009) |
| Debt and equity problems | (Irfan et al. 2019; Sharma and Sinha 2019) |
| Competition among different energy sources | (Goel 2016) |
| Technological barriers (TCN) | (Gebreslassie 2021; Irfan et al. 2019) |
| Inefficient domestic technology | (Nordensvard, Zhou, and Zhang 2018; Shammugam et al. 2019) |
| Lack of production facilities | (Hayashi 2018) |
| Reliance on foreign economies for key equipment | (Lucena and Lucena 2019; Quitzow, Huenteler, and Asmussen 2017) |
| Lack of R&D activities | (Esdand 2017; Sharma and Sinha 2019) |
| Lack of professional workforce | (Ren et al. 2014; Wang, Guo, and Huang 2011; Wu and Hong 2007) |
| Inefficient wind turbine technology | (Diógenes et al. 2020; Luthra et al. 2015) |
| Inappropriate forecasting and scheduling techniques | (Wang, Xu, and Yuan 2021) |
| Infrastructure barriers (IFS) | (Diógenes et al. 2020; Tang, Taylor, and Mahalingam 2013) |
| Land acquisition complexity | (Irfan et al. 2019; Kulkarni and Anil 2018) |
| Inaccessibility to railway and highways | (Jangid et al. 2016; Kulkarni and Anil 2018) |
| Transmission and distribution (T&D) losses | (Burke et al. 2019; Sadovskaia et al. 2019) |
| Old grid configuration | (Yadav, Davies, and Palit 2019) |
| Absence of institutional framework | (Diógenes et al. 2020; Badri et al. 2019) |
| Inadequate grid infrastructure | (Wang, Xu, and Yuan 2021) |
| Undeveloped market infrastructure | (Diógenes et al. 2020; Tang, Taylor, and Mahalingam 2013) |
| Policy & regulatory barriers (PLR) | (Irfan et al. 2019; Kulkarni and Anil 2018) |
| Lack of a comprehensive wind power policy | (García-Alvarez, Cabeza-García, and Soares 2017; C.R. Kumar et al. 2019; Xia, Lu, and Song 2020) |
| Unbalanced feed-in-tariff (FIT) | (Joly, Spodnja, and Raven 2016; Zárate-Toledo, Patiño, and Fraga 2019) |
| Political instability | (deCastro et al. 2019; Herrera, Cosenz, and Dyner 2019; Prakash 2018) |
| Lack of coordination and decision-making | (NF Da et al. 2013; Wong 2005) |
| Unsatisfactory regulatory structure | (González and Lacal-Árântegui 2016; Ho 2016) |
| Lack of a political framework | (González and Lacal-Árântegui 2016; Ho 2016) |
| Unappealing policies to attract foreign direct investment | (Gebreslassie 2021; Keeley and Ikeda 2017) |
| Socio-cultural barriers (SCL) | (Hevia-Koch and Ladenburg 2019; Hübner et al. 2019; Schäffer et al. 2019) |
| Noise and visual impact | (Li et al. 2020; Martin et al. 2018; Nazir et al. 2020; Stokke et al. 2020; Łopucki, Klich, and Gielarek 2017) |
| Adverse impact on wildlife and birds | (Phadke, Park, and Abhyankar 2019; Thapar, Sharma, and Verma 2018) |
| Preference for conventional electricity | (Ali and Gasi 2017; Chaurasiya, Warudkar, and Ahmed 2019; Milikan and Carney 2013) |
| High corruption | (Chinnmoy, Inijian, and Goic 2019; Zarei et al. 2019) |
| Lack of awareness about wind energy benefits | (Chinnmoy, Inijian, and Goic 2019; Zarei et al. 2019) |
| Uneven profit distribution among stakeholders | (Iglesias, Del Río, and Já 2011; Zhou et al. 2012) |
| Historical land is occupied by wind farms | (Fast and Mabee 2015; Sharma and Sinha 2019) |

coordination and decision-making, unsatisfactory regulatory structure, lack of a political framework, and unappealing policies to attract foreign direct investment. Socio-cultural barriers include noise and visual impact, adverse impact on wildlife and birds, preference for conventional electricity, high corruption, lack of awareness about wind energy benefits, uneven profit distribution among stakeholders, and historical land occupied by wind farms.

Even though countries may confront similar barriers, the wind sector’s development could be influenced by a country’s unique geographical position, climate, culture, and financial circumstances (Huesca-Pérez, Sheinbaum-Pardo, and Köppel 2016). Thus, it is critical for each country’s wind program to identify and overcome its unique barriers. The previous investigations identified a literature gap about the critical barriers impeding the Indian wind power sector. For instance, some
studies have examined wind energy programs with the goal of determining the functions of technical innovation, efficacy, and the influence of wind technology implementation (Bento and Fontes 2019; Edsand 2017), while others have examined the reasons for wind energy’s slow growth (Chaurasiya, Warudkar, and Ahmed 2019; Dong et al. 2018; Razzaq, Fatima, and Murshed 2021; Sun et al. 2022).

While several barriers were identified, previous works did not comprehensively focus on examining and comprehending the critical barriers impeding the Indian wind power growth. Additionally, they lacked an in-depth examination and priority assessment of the barriers. Prioritizing barriers enables decision-makers to make appropriate choices to tackle real-life challenges. The current study attempts to emphasize all critical barriers in terms of their significance. Additionally, it proposes strategic policies for India’s wind energy expansion. Along these lines, this study may assist stakeholders and policymakers in identifying the wind energy development barriers and finding alternative solutions for its smooth growth.

3. Materials and methods

The current study employs a hybrid research methodology that includes three distinct stages. The first stage identifies numerous wind energy barriers through an extensive literature review. To better understand these barriers, energy reports, journal articles, policy studies, and monitoring frameworks were extensively studied (IDFC 2010; MNRE 2010, 2021, 2022). Following that, the modified Delphi method is employed to refine and classify those barriers using experts’ feedback. The Delphi process offers three key benefits. First, it draws on the experience of experts. Second, it documents facts along with personal preferences and expectations. Finally, the technique avoids the pitfalls of face-to-face interaction (Scala and McGrath 1993).

In the second step, a pair-wise comparison matrix is generated by employing the AHP approach to calculate the weights, assigned to each barrier. AHP is a widely used Multi-Criteria Decision-Making (MCDM) method for resolving difficult decision-making issues. The method is adopted to solve complicated problems by employing a simple hierarchical pattern. Besides, it takes into account scientific facts, objective evaluations, and technical expertise when making decisions (Potić et al. 2021).

The final stage prioritizes alternatives for overcoming those barriers by employing the G-TOPSIS method. G-TOPSIS performs well in a wide variety of application domains and has garnered considerable attention from scholars around the globe (Irfan et al. 2022). This approach requires simple computation and a little calculation time, classifies the substitutes, integrates tangible and intangible factors, and is responsible for verifying the degree of position of alternatives. G-TOPSIS is widely considered as the best decision-making methods due to its application and practicality (Tiwari and Kumar 2021). Furthermore, it is suitable for a variability of different circumstances and objectives. Key advantages of G-TOPSIS on standard MCDM methods are adaptability, rationality, and legibility, allowing the successful implementation of substitutes to be measured by computations (Rehman et al. 2021). The research framework is illustrated in Figure 2.

3.1. Modified delphi method

This method has been employed for refining and classifying barriers, as it systematically collects experts’ feedback using questionnaires and discussion. Professionals from diverse fields discuss their thoughts, sentiments, and proficiency (Revez et al. 2020). The technique comprises five basic steps. The first step consists of selecting specialists; a two round of questionnaires survey is performed in the 2nd and 3rd step; the experts’ feedback is filtered in the fourth step, while barriers are finalized in the last step based on experts’ feedback (Quyên 2014).

Scholars have different viewpoints regarding the selection criteria of experts while employing this method. For instance, the Delphi method requires selecting a panel of experts on the subject under study. An expert is someone who possesses the knowledge and experience necessary to participate in a group discussion. Expertise, however, is the desired goal for panel selection, and it is this feature that sets the Delphi method different from other general forms of survey research (Clayton 1997). Experts can be selected based on their qualifications and ability to contribute information during the discussion. The panel may be big or small, local, state, national, or international. Group size may also depend on the purpose of the study,
complexity, and level of required expertise (Uhl 1983). Although group size varies, some general guidelines suggest 15–30 experts for a homogeneous population, i.e., experts from the same discipline and 5–10 people for a heterogeneous population, i.e., people with expertise in a particular subject but from different social/professional strata (Delbecq, de Ven AH, and Gustafson 1975; Moore 1987). Along these lines, Okoli and Pawlowski (2004) asserted that this approach efficiently synthesizes the opinions of 10 to 18 experts. In light of these arguments, we invited 17 experts; however, 15 of them (response rate: 88%) expressed their interest and participated in this study.

3.1.1. Selection of the expert consensus panel
In light of the country’s continuing COVID-19 epidemic and lockdown scenario, we administered an online survey with experts and added their perspectives. These experts belong to academia, industries, and government sectors and have vast professional experience in the relevant fields. Three independent stages were used to collect data. The first stage was contacting experts through e-mails and obtaining their consent to participate in the study. This phase comprised a thorough discussion of the study’s aims with the participants. The selection of experts was determined using the following criteria: Firstly, senior professionals from academia as well as industries and government sectors. Secondly, they must have a minimum of 10 years of professional experience. Finally, they should possess an education equivalent to bachelors. Appendix A (Table S.1) provides experts’ profile included in this study. Before Delphi consensus voting, several video conferences were performed among the experts in order to present the comprehensive procedure and address their questions. For confidentiality, experts’ identities and their individual votes were kept hidden among themselves so that they would not have to worry about making contradictory selections with others. The selection criteria for experts demonstrate that they come from heterogenous disciplines. Given that the sample is rich enough, and the findings drawn on this sample are reliable.
3.1.2. Process of the Delphi consensus vote

Experts provided their perspectives by examining the essential roles of barriers in hindering India’s wind power growth (see Table S. 2 of supplementary materials). They were directed to make a judgment on each item based on their expertise and practical experience. The experts’ responses about each item were assessed using a three-option query (Agree, Neutral, and Disagree). The Delphi consensus vote results are presented in the form of percentages. The second stage further consists of two rounds. During the first round, a one-week time was provided to experts to finish their answers. During the second round, a one-week time was again given to them to seek their mutual consent regarding all questionnaire items. Prior notice was sent to all experts between all questionnaire rounds. Seeking the mutual consent of all experts and decision-makers is a pivotal step of the modified Delphi method to achieve accuracy and consistency (Ikram, Sroufe, and Zhang 2020). Previous research suggests that the threshold for respondent agreement should exceed 80% (Hohmann et al. 2020). If the threshold of agreement is ≤80%, it signified that the item lacks agreement and requires another subsequent round to attain a greater agreement level or no consensus (Hasson, Keeney, and McKenna 2000). The final stage collected and finalized the responses from experts.

3.2. Analytical Hierarchy process

We proceed with the AHP analysis using SuperDecisions V3.2 software. AHP is one of the most adaptable MCDM methods to resolve complex decision-making issues. Saaty introduced this method in the 1970s (Saaty 1977). AHP emphasizes the importance of experts’ instinctive judgments and prioritization during the decision-making process (see Table 5). The method is used to quantify experts’ relative priorities by employing Saaty’s 1–9 AHP scale. More precisely, experts rate their opinions to the criteria regarding their importance ranging from 1 to 9, as 1 indicates “equal importance” and 9 indicates “extreme importance” (see Table S. 3 of supplementary materials). The major feature of AHP is pairwise comparisons, which validate the correctness of different priorities (Mingyu, Shizhong, and Yibo 2020). The technique aids in making sound choices and prioritizing difficult challenges. The method can be divided into the following steps (Saaty 1990):

**Step 1.** Establishing the hierarchical structure of problem: The hierarchical structure of the problem is established during this phase.

**Step 2.** Experts’ opinion collection: Experts’ opinions are assigned numerical values. Later, using Saaty’s 1–9 scale, a pairwise comparison matrix is generated.

**Step 3.** Determining Consistency Index: The consistency of pairwise comparison matrix is determined in this step by employing Consistency Index (CI) as follows:

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1}
\]

(1)

Here, \(\lambda_{\text{max}}\) denotes the eigenvalue and \(n\) denotes the no. of major criteria.

**Step 4.** The calculation of Consistency Ratio: The Consistency Ratio (CR) is calculated during this phase and is represented as:

\[
CR = \frac{CI}{RI}
\]

(2)

| Sr. No | Linguistic variables      |
|-------|---------------------------|
| 1     | Equal importance (EI)     |
| 3     | Moderate importance (MI)  |
| 5     | Strong importance (SI)    |
| 7     | Very strong importance (VI)|
| 9     | Extreme importance (EI)   |
| 2,4,6,8 | Middle values            |
Here, $RI$ denotes Random Index (see Table 6). The primary criterion that should be addressed while performing pairwise comparisons is that the CR value should be less than 0.1, as higher values compromise the results (Ikram et al. 2019). The AHP matrix results of our study indicate that the CR ratio is within this recommended range, implying that we do not have inconsistency matrix issues.

### 3.3. Grey system theory

Professor Julong Deng developed the principles of Grey systems theory in 1982 (Liu, Forrest, and Yang 2011). The theory addresses and solves the discrete and incomplete data ambiguity problems with an objective to overcome the gap between natural and social sciences. Grey systems are named based on the transparency amount of data. If the system data is completely known, then it is called the white system, and if the system data is entirely unknown, the black system is called. The term white system is used when there is full recognition of system data, while the term black system is used when there is no recognition of system data (Javanmardi and Liu 2019). On the other hand, the system is called a gray system if some portion of the data is recognized, and the rest is unrecognized (Mahmoudi et al. 2019). Because of researchers’ arbitrary and ambiguous opinions, the present study has employed the G-TOPSIS approach. This approach yields satisfactory results by utilizing input data.

### 3.4. Grey numbers

Grey number is regarded as the intermission of specified and unspecified values. The interval usually contains missing system data. The $\otimes$ symbol is used to denote the gray numbers. Grey numbers have multiple categories (Liu, Yang, and Forrest 2017); however, the present study has proposed three categories.

**Category (1)**: If a gray number is exclusively determined by its lower bound, it is referred to as a lower bound, such as $\otimes A = [A, \infty)$.

**Category (2)**: If a gray number is exclusively determined by its upper bound, it is referred to as an upper bound, such as $\otimes A = (\infty, \bar{A}]$.

**Category (3)**: If a gray number is determined by upper bound and lower bound, it is referred to as an interval gray number, such as $\otimes A = [A, \bar{A}]$.

Arithmetic functions could be done on two gray numbers having values $\otimes A = [A, \bar{A}]$ and $\otimes B = [B, \bar{B}]$ and shown in Equations (3–6) as follows:

$$\otimes A + \otimes B = [A + B, \bar{A} + \bar{B}]$$

(3)

$$\otimes A - \otimes B = \otimes A + (- \otimes B) = [A - B, \bar{A} - \bar{B}]$$

(4)

$$\otimes A \times \otimes B = \left[\min\{AB, \bar{A}B, \bar{A}\bar{B}, \bar{A}\bar{B}\}, \max\{AB, \bar{A}B, \bar{A}\bar{B}, \bar{A}\bar{B}\}\right]$$

(5)

$$\frac{\otimes A}{\otimes B} = \otimes A \times \otimes B^{-1} = \left[\min\left\{\frac{A}{B}, \frac{\bar{A}}{\bar{B}}, \frac{\bar{A}}{\bar{B}}, \frac{\bar{A}}{\bar{B}}\right\}, \max\left\{\frac{A}{B}, \frac{\bar{A}}{\bar{B}}, \frac{\bar{A}}{\bar{B}}, \frac{\bar{A}}{\bar{B}}\right\}\right]$$

(6)

Equation (7) provides the length of gray number $\otimes A = [A, \bar{A}]$ as:

$$L(\otimes A) = \bar{A} - A$$

(7)

| Table 6. Random Index $(RI)$.

| n  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $RI$ | 0.00 | 0.00 | 0.058 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |
If $\otimes A = [A, \bar{A}]$ and $\otimes B = [B, \bar{B}]$ are 2 gray numbers; the degree of grayness is determined using the equation (8).

$$P\{\otimes A \leq \otimes B\} = \frac{\text{Max}\{0, L^* - \text{Max}(0, \bar{A} - B)\}}{L^*}$$  (8)

Here $L^* = L(\otimes A) + L(\otimes B)$

### 3.5. Grey technique for order preference by similarity to ideal solution

By employing $m$ parameters, this approach estimates $n$ alternatives. The fundamental reason of this approach establishes the ideal positive and negative alternatives. An ideal alternative is one that is closest to the optimal positive solution and farthest from the optimal negative option. The gray theory takes into account inconsistencies, as the data are not consistent sometimes. The different steps of the G-TOPSIS method are presented in the following stages (Sadeghi, Razavi, and Saberi 2013).

**Step 1:** In this step, experts determine the weighting of each criterion. Based on linguistic variables, their input is expressed using gray theory. Assuming there are $k$ experts, Equation (9) determines the weight of criteria $j$.

$$\otimes w_j = \frac{1}{k} \left[ \otimes w_j^1 + \otimes w_j^2 + \ldots + \otimes w_j^k \right]$$  (9)

**Step 2:** The linguistic variables are used to rank the alternatives in this step. If $k$ denotes decision-makers in criterion $j$, then alternative value $i$ is regulated as:

$$\otimes G_{ij} = \frac{1}{k} \left[ \otimes G_{ij}^1 + \otimes G_{ij}^2 + \ldots + \otimes G_{ij}^k \right]$$  (10)

**Step 3:** This step yields the gray decision matrix and is denoted by the following Eq.

$$D = \begin{bmatrix}
\otimes G_{11} & \otimes G_{12} & \ldots & \otimes G_{1n} \\
\otimes G_{21} & \otimes G_{22} & \ldots & \otimes G_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\otimes G_{m1} & \otimes G_{m2} & \ldots & \otimes G_{mn}
\end{bmatrix}$$  (11)

Here, $\otimes G_{ij}$ articulates the implication of $i$ in $j$ criterion.

**Step 4:** The gray decision matrix is normalized in this step and represented as follows:

$$D^* = \begin{bmatrix}
\otimes G_{11}^* & \otimes G_{12}^* & \ldots & \otimes G_{1n}^* \\
\otimes G_{21}^* & \otimes G_{22}^* & \ldots & \otimes G_{2n}^* \\
\vdots & \vdots & \ddots & \vdots \\
\otimes G_{m1}^* & \otimes G_{m2}^* & \ldots & \otimes G_{mn}^*
\end{bmatrix}$$  (12)

Equation (13) is used for normalization if the criteria are benefit characteristics.

$$G^*_{ij} = \left[ \frac{G_{ij}}{G_{ij}^{\text{max}}} \right] \frac{G_{ij}^{\text{max}}}{\bar{G}_j} \quad \text{Where} \ G_{ij}^{\text{max}} = \text{max}_{1 \leq j \leq m} \{ \bar{G}_j \}$$  (13)

Normalization is represented in Equation (14) as follows:

$$G^*_{ij} = \left[ \frac{G_{ij}^{\text{min}}}{G_{ij}} \right] \frac{G_{ij}}{\bar{G}_j} \quad \text{Where} \ G_{ij}^{\text{min}} = \text{min}_{1 \leq j \leq m} \{ \bar{G}_j \}$$  (14)

Following normalizing, energy matrix values are within $[0, 1]$ interval.

**Step 5:** Equation (15) represents gray-weighted normalized decision matrix.


\[
V = \begin{bmatrix}
\otimes V_{11} & \otimes V_{12} & \ldots & \otimes V_{1n} \\
\otimes V_{21} & \otimes V_{22} & \ldots & \otimes V_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\otimes V_{m1} & \otimes V_{m2} & \ldots & \otimes V_{mn}
\end{bmatrix}
\]

Where \( \otimes V_{ij} = \otimes G_{ij}^* \times \otimes w_j \) (15)

**Step 6:** This step calculates the ideal positive and negative solutions using Equation (16) and Equation (17).

\[
S^{\text{max}} = \{ \max_{1 \leq j \leq m} V_{i1}, \max_{1 \leq j \leq m} V_{i2}, \ldots, \max_{1 \leq j \leq m} V_{in} \}
\]

\[
S^{\text{min}} = \{ \min_{1 \leq j \leq m} V_{i1}, \min_{1 \leq j \leq m} V_{i2}, \ldots, \min_{1 \leq j \leq m} V_{in} \}
\]

**Step 7:** The potential grayness degree between optimal and alternative solutions is calculated in this step following Equation (18).

\[
P\{S_i \leq S^{\text{max}}\} = \frac{1}{n} \sum_{j=1}^{n} P\{ \otimes V_{ij} \leq \otimes G_{ij}^{\text{max}} \}
\]

**Step 8:** The possibilities are ordered by the values obtained in the previous step in ascending order. Preference is given to the option with the least amount of grayness.

4. Results

The application of modified Delphi, AHP, and G-TOPSIS methods led stakeholders, developers, and policymakers to identify and overcome wind energy barriers. Besides, this assessment offers the groundwork for planners and decision-makers to further define the research agenda for this subject while also offering a compelling rationale for the quick development of wind energy.

4.1. Results of modified Delphi

A total of 15 experts accepted our invitation and participated in all two rounds of the Delphi survey votes. There were 25 items on the first list for consensus voting. Following the two-round Delphi vote, 6 of 25 items (24%) achieved complete consensus, while the remaining 19 items achieved more than 80% expert agreement. Expert consensus was reached on 22 of 25 questions in the first round (Figure 3), and the remaining 3 questions were voted once more in the next round (Figure 4), which likewise achieved consensus threshold. Based on these responses, new items were not proposed during the two-round voting. As a result, the final version of expert consensus had a total of 25 items. These items addressed the most significant and contentious barriers to wind energy development, which were classified into five major dimensions: (i) financial, (ii) technological, (iii) infrastructure, (iv) policy & regulatory, and (v) socio-cultural barriers. In Table S. 2 of the supplemental materials, the finalized expert consensus elements are listed in detail.

4.2. Results of analytical Hierarchical process

As a next step, we conducted AHP pairwise comparison matrices to compute specific weight scores by employing geometric mean. In this regard, we calculated the weights of barriers using experts’ input. More specifically, the first step computes the weights of major barriers, whereas the second step computes the weights of sub-barriers. Figure 5 illustrates the hierarchical pattern of barriers.
4.2.1. Major barriers’ ranking

The AHP method computes the weights of entire barriers. As shown in Table 7, the financial barrier is the high priority barrier with 0.494 weight, obstructing the progress of the Indian wind power sector. Figure 6 shows the schematic diagram of all major barriers. Technological barrier ranks second with 0.235 weight. The recent technology developments, regulations, and monitoring mechanisms would remain the primary issues for the wind industry. To maintain sustainable operations, the wind power industry needs to continuously implement new procedures (Vallecha et al. 2020).

Based on the weight estimation, the third priority has been given to the infrastructure category, having a weight of 0.124. The country has small manufacturing facilities and depends on foreign economies for essential equipment to build modern wind farms (Shidore and Busby 2019), hindering India’s smooth utilization of wind energy (Bedi 2019). Policy & regulatory are the next barrier in this context, having a weight of 0.099. The lack of an integrated policy and regulatory frameworks for the wind sector has negative effects on Indian wind energy’s rapid growth. In addition, as time passes, certain government policies require amendments (Shukla et al. 2018).

Finally, socio-cultural is the least critical barrier, with the lowest weight of 0.049. The lack of awareness about wind energy benefits, high corruption, noise, visual impact, and adverse impact on wildlife and birds are the main reasons of this barrier (Chaurasiya, Warudkar, and Ahmed 2019; Nazir et al. 2020).

CR = 0.030


4.2.2. Ranking of sub-barriers

A pairwise comparison matrix is created after developing the hierarchical structure (see Tables D1–D5 of Appendix D). This section addresses the results of sub-barriers (see Figure 7–11).

**Financial:** This group ranks sub-barriers in the following order: FNL-2 > FNL-5 > FNL-1 > FL-4 > FNL-3 and is shown in Figure 7. Based on weight distribution, limited government subsidy (FNL-2) is the top-ranked sub-barrier, weighing 0.510. The second important sub-barrier is the high initial cost (FNL-5), with a weight of 0.174. High duties on importing foreign equipment (FNL-1) placed next in this group, with 0.124 weight. The government has slapped steep import taxes on wind equipment. As a result, wind energy schemes have become uneconomical in the country (Raina and Sinha 2019).

Limited share of foreign investment (FNL-4) is the subsequent important barrier by securing 0.119 weight. International investors are afraid to participate in the Indian wind power sector because the Indian government has announced high levels of interest rates (Keeley and Matsumoto 2018). On the contrary, foreign investments are reported to have an integral role in advancing clean energy technologies (Ahmad, Jabeen, and Wu 2020). Absence of financial framework (FNL-3) obtained the lowest weight of 0.073 in this category. Lolla, Roy, and Chowdhury (2015) analyzed the Indian wind power sector from various perspectives and disclosed that the absence of a financial framework is preventing the steady growth of wind energy.

**Technological:** Sub-barriers under this category are prioritized as follows: TCN-1 > TCN-2 > TCN-5 > TCN-4 > TCN-3 (see Figure 8). Inefficient domestic technology (TCN-1) is the top influential sub-barrier having 0.375 weight. Wind technology is inevitable, owing to the country’s lack of modern wind technology, and the locally manufactured equipment is unreliable (Goel 2016). Lack of production facilities (TCN-2), having 0.315 weight, got second place. Reliance on other countries (TCN-5) ranks third with a weight of 0.118. India is dependent on other economies for crucial parts due to inefficient domestic technology and lack of production facilities (Nordensvard, Zhou, and Zhang 2018). Importing crucial parts from abroad puts a heavy burden on the national
budget and slows down the domestic growth of renewables. In the same vein, Shammugam et al. (2019) illustrated that Germany was struggling in the wind energy development process due to the importation of raw materials, like Copper and Dysprosium (used as key materials in wind turbine manufacturing).

Lack of R&D activities (TCN-4) placed at fourth position in the list by securing 0.117 weight. The Indian wind power sector requires continuous R&D activities to get a competitive advantage over other renewables (Hayashi 2018). Lack of professional workforce (TCN-3) got the last place in this dimension, with the lowest weight of 0.075. Contrastingly, the Chinese wind sector has gained a competitive advantage owing to the booming International technological transfer (Quitzow, Huenteler, and Asmussen 2017).

**Infrastructure:** This dimension ranks sub-barriers as follows: IFS-3 > IFS-5 > IFS-4 > IFS-1 > IFS-2 and is shown in Figure 9. Land acquisition complexity (IFS-3) is the prevailing sub-barrier, having 0.494 weight. Inaccessibility to railway and highways (IFS-5) got next position by receiving 0.219
weight. The next major sub-barrier is transmission and distribution (T&D) losses (IFS-4) by obtaining 0.115 weight. T&D losses as a share of electricity output fell from 27% to 19% in India from 2000 to 2014 (Burke et al. 2019). The common reasons for T&D losses are poor management, electricity theft, and less monitoring (Sadovskaia et al. 2019).

Old grid configuration (IFS-1) ranks fourth, with 0.100 weight. This is confirmed by literature since the old grid configuration of the country mostly supports traditional thermal energy (Irfan et al. 2020). A significant investment is required for the current grid structure to facilitate wind energy in the long run.
The upgradation of the old grid configuration would involve high capital costs that would prove an enormous burden to a developing country. Finally, with 0.090 weight, the absence of institutional framework (IFS-2) got last place within this category. No institutional mechanisms are available to provide wind-based after-sales services. The private sector’s limited participation cannot encourage the existing institutional instruments to adjust in new markets (Luthra et al. 2015).

Figure 8. Technological sub-barriers ranking.

Figure 9. Infrastructure sub-barriers ranking.
**Policy & regulatory:** This dimension prioritizes barriers in the following order: PLR-1 > PLR-3 > PLR-2 > PLR-5 > PLR-4 (see Figure 10). With a weight of 0.433, the lack of a comprehensive wind power policy (PLR-1) ranked top-one under this dimension. Unbalanced FIT (PLR-3) got second place, with 0.261 weight, while political instability (PLR-2) ranked third, with a weight of 0.165.

The country has enormous wind power potential; however, a strong political commitment is needed to harness this potential. Political uncertainty is impeding wind energy deployment in the country (Jolly, Spodniak, and Raven 2016). The lack of coordination and decision-making (PLR-5) is the next barrier within this dimension, with 0.106 weight. The main government agencies, including the Ministry of New and Renewable Energy and the Indian Renewable Energy Development Agency are charged with distinct functions and obligations that require them to engage in joint decision-making. Nonetheless, these organizations lack synchronization and information sharing, impeding the speedy growth of wind power sector (Prakash 2018). Unsatisfactory regulatory structure (PLR-4) obtained weight of 0.035 and ranked last under policy and regulatory barriers.

**Socio-cultural:** Sub-barriers within this group are ranked in the following order: SCL-1 > SCL-2 > SCL-4 > SCL-3 > SCL-5 and presented in Figure 11. Noise and visual impact (SCL-1) is the top barrier by securing a maximum 0.440 weight. Noise impact is defined as people’s negative perceptions about the sound generated during the normal functioning of wind farms (Hübner et al. 2019). In contrast, the visual impact is defined as the people’s negative attitudes about wind turbines in a particular landscape range (Hevia-Koch and Ladenburg 2019). Adverse impact on wildlife and birds (SCL-2) received 0.233 weight and ranked second within this domain. Wind energy schemes seriously threaten wildlife and birds (Nazir et al. 2020). Preference for conventional electricity (SCL-4) placed third within this group, having 0.158 weight. Entrepreneurs in India consider that wind power schemes are unprofitable here relative to other economies. The fundamental rationale is the low unit price of fossil fuel-based electricity (Thapar, Sharma, and Verma 2018). As the electricity generated from wind farms is costly, inhabitants show hesitation in buying it (Phadke, Park, and Abhyankar 2019).

High corruption (SCL-3) is the succeeding barrier in this group, having 0.093 weight. This issue has been extensively reported by researchers in various investigations. Ali and Gasmi (2017) demonstrated that corruption is India’s biggest impediment to economic growth. One classic example of this lack of transparency is the “Coalgate” or coal allocation scam. The last in this category is the lack of awareness about wind energy benefits (SCL-5) with a weight of 0.0037.

![Figure 10. Policy & regulatory sub-barriers ranking.](image-url)
4.2.3. **Overall ranking of sub-barriers**

Table 8 reports the overall ranking of sub-barriers while Figure 12 graphically represents this ranking. The ranking is as follows: FNL-2 > TCN-1 > FN-5 > TCN-2 > FNL-3 > FNL-4 > PLR-1 > FNL-3 > TCN-5 > TCN-4 > IFS-5 > PLR-3 > SCL-1 > TCN-3 > PLR-2 > IFS-4 > IFS-1 > SCL-2 > IFS-2 > PLR-5 > SCL-4 > SCL-3 > SCL-5 > PLR-4.

It is obvious that limited government subsidy is the top influencing sub-barrier with 0.2519 weight. Inefficient domestic technology (0.0881) ranked second, while high initial cost (0.0860) and lack of production facilities (0.0740) are the next important sub-barriers, respectively. On the other hand, preference for conventional electricity (0.0077), high corruption (0.0045), lack of awareness about wind energy benefits (0.0037), and unsatisfactory regulatory structure (0.035) are the least important sub-barriers.

4.3. **Results of G-TOPSIS**

This method is employed to evaluate the four key alternatives such as reformations in policy framework (A1), availability of adequate funds (A2), improvement of R&D activities (A2), and development of infrastructure (A4). The ordering matrices of linguistic variables are generated following the comparison of alternatives. Table 9 summarizes the outcomes of the positive and negative gray ideal solutions. Finally, the degree of grayness is computed between ideal and alternative solutions, as reported in Equation (19–22).

\[
P_1(S_1 \leq S^{\text{max}}) = 0.531 \tag{19}
\]
\[
P_2(S_2 \leq S^{\text{max}}) = 0.371 \tag{20}
\]
\[
P_3(S_3 \leq S^{\text{max}}) = 0.664 \tag{21}
\]
Table 8. Sub-Bariers’ final ranking.

| Major barriers | Weight | Codes of sub-barriers | Consistency Ratio (CR) | Local weight | Global weight | Overall rank |
|----------------|--------|------------------------|------------------------|--------------|---------------|--------------|
| Financial      | 0.494  | FNL-1                  | 0.0427                 | 0.124        | 0.0613        | 5th          |
|                |        | FNL-2                  | 0.510                  | 0.2519       | 1st           |              |
|                |        | FNL-3                  | 0.073                  | 0.0360       | 9th           |              |
|                |        | FNL-4                  | 0.119                  | 0.0588       | 2nd           |              |
|                |        | FNL-5                  | 0.174                  | 0.0860       | 3rd           |              |
| Technological  | 0.235  | TCN-1                  | 0.0681                 | 0.375        | 0.0881        | 2nd          |
|                |        | TCN-2                  | 0.315                  | 0.0740       | 4th           |              |
|                |        | TCN-3                  | 0.075                  | 0.0176       | 15th          |              |
|                |        | TCN-4                  | 0.117                  | 0.0275       | 11th          |              |
|                |        | TCN-5                  | 0.118                  | 0.0277       | 10th          |              |
| Infrastructure | 0.124  | IFS-1                  | 0.0073                 | 0.096        | 0.0119        | 18th         |
|                |        | IFS-2                  | 0.090                  | 0.0112       | 20th          |              |
|                |        | IFS-3                  | 0.494                  | 0.0612       | 6th           |              |
|                |        | IFS-4                  | 0.100                  | 0.0124       | 17th          |              |
|                |        | IFS-5                  | 0.219                  | 0.0271       | 12th          |              |
| Policy & regulatory | 0.099  | PLR-1                  | 0.0392                 | 0.433        | 0.0429        | 8th          |
|                |        | PLR-2                  | 0.165                  | 0.0163       | 16th          |              |
|                |        | PLR-3                  | 0.261                  | 0.0259       | 13th          |              |
|                |        | PLR-4                  | 0.035                  | 0.0035       | 25th          |              |
|                |        | PLR-5                  | 0.106                  | 0.0105       | 21st          |              |
| Socio-cultural | 0.049  | SCL-1                  | 0.0418                 | 0.440        | 0.0215        | 14th         |
|                |        | SCL-2                  | 0.233                  | 0.0114       | 19th          |              |
|                |        | SCL-3                  | 0.093                  | 0.0045       | 23rd          |              |
|                |        | SCL-4                  | 0.158                  | 0.0077       | 22nd          |              |
|                |        | SCL-5                  | 0.076                  | 0.0037       | 24th          |              |

\[ P_4(S_4 \leq S_{\text{max}}) = 0.522 \] (22)

Equation (23) provides the final ranking of alternatives based on the above-mentioned equations as follows:

\[ P_2 > P_5 > P_1 > P_3 \] (23)

G-TOPSIS improves decision-making precision in unpredictable circumstances. It is obvious from Table 9 that the availability of adequate funds is the top alternative to tackle wind energy barriers by securing 0.371 weight, followed by the development of infrastructure (0.522) Similarly, reforms in the policy framework (0.531) and enhancing R&D activities (0.664) are the third and fourth important alternatives, respectively.

4.4. Sensitivity analysis

Finally, a sensitivity analysis is held to show the effect of altering different parameters of the model on the choice of the best alternative to wind energy development barriers. Origin software was used to perform this analysis to examine the changes in outcome caused by a change in each of the main criteria. The aim of sensitivity analysis is to check the robustness of the results and explore how these changes affect the priorities of the selected alternatives (Maletič et al. 2014). Alternatives’ new ranking is presented in Fig. 12. “A” denotes the original weight, whereas “W” denotes the new weight. A series of tests were conducted by altering experts’ input to compare the ranking obtained from G-TOPSIS and sensitivity analysis. A similar ranking of alternatives was obtained by changing the value of the degree of grayness. However, the weights of W1 (0.613) and W4 (0.591) alternatives are slightly changed, whereas the weights of W2 (0.371) and W3 (0.664) are constant.
Following sensitivity analysis, alternatives are ranked in the following order: \( P_2 > P_5 > P_1 > P_3 \). It is obvious from Figure 13 that the availability of adequate funds and the development of infrastructure are the optimal solution to overcome the barriers of wind energy development. Whereas reformations in the policy framework and enhancing R&D activities are considered to have the least influence. Overall, the sensitivity analysis results showed that the ranks of the alternatives remained stable in all cases. These results show that the model is stable and robust and thus appropriate for the decision-making process.

5. Discussion

The results of the modified Delphi method indicate a total of 25 wind energy development barriers, which were then classified into five major dimensions. Following the two-round modified Delphi method, all 25 items achieved more than 80% expert agreement, which is in line with the findings of (Hohmann et al. 2020). According to the AHP analysis, the financial category has been accorded the highest priority, with 0.494 weight. Given that India is a developing economy, it is not surprising that financial barriers received the greatest attention in expert opinions. Technological and infrastructure
barriers were moderately significant to wind energy development, with priority scores of 0.235 and 0.124, respectively. These results are in accordance with Ikram et al. (2019), as the authors ranked technical barriers at third place and opined that they are moderately important to the acceptance of green technologies in the Pakistani context. In another study, Diógenes et al. (2020) examined barriers to onshore wind energy implementation through a systematic review process and found that institutional barriers moderately influence onshore wind energy implementation.

Policy & regulatory barriers were also found to be significant ones by securing a priority weight of 0.099 and placed at 4th position in the major barriers category. The research findings of Richards, Noble, and Belcher (2012) support this result. The authors observed barriers to renewable energy development in the Canadian context and specified political barriers as the most significant barriers to renewable energy development. In the same vein, González and Lacal-Arántegui (2016) scrutinized potential barriers for wind energy deployment in the European Union Member States and revealed that the stability of regulatory framework is one of the most important concerns for wind energy deployment in these states. The least critical category was identified as sociocultural barriers, with a priority score 0.049. This result is supported by the study outcomes of Mukeshimana et al. (2021), as the authors indicated that socio-cultural barriers is the least important barrier to biogas dissemination by obtaining a weight of 0.05.

Comparing the relative importance of barriers within each category revealed that limited government subsidy (overall priority of 0.2519) is the most significant barrier within the financial category.

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**Figure 13.** Sensitivity analysis-based final ranking of alternatives.
Regardless of its remarkable growth, the Indian wind sector is facing certain obstacles, including a high dependency on government subsidies (Plutshack et al. 2019). Government subsidies for new developers are very difficult to get. Financial institutions face limited exposure to wind energy projects due to the massive capital already committed to thermal energy sources (Burke et al. 2019). On the other hand, the global wind energy sector is undergoing significant rebuilding and adjustment as a result of government subsidies designed to maximize value conversion (Qu et al. 2017). In another study, Irfan et al. (2019) conducted semi-structured interviews with industry professionals about various elements of wind energy and found that 19% of interviewees believe that the lack of government subsidies is a significant impediment to the growth of the wind sector in India. They think that the majority of wind energy developers rely on government subsidies and are commercially unviable without them. In this regard, it has been suggested that the absence of government subsidies is a major hurdle to the development of wind energy generation in India. High initial cost (overall priority of 0.086) also acts as a major impediment to wind energy development. Previous research also supports this fact, as (Diógenes et al. 2020) argued that installing wind projects requires a massive initial investment, which is a significant hindrance to the wind energy sector. In comparison to other renewable energy sources, wind energy is a little expensive and needs a high initial cost. While wind energy costs have decreased dramatically over the years, they remain expensive in developing nations such as India, which encourages thermal energy usage.

Inefficient domestic technology (0.0881) was the most influencing barrier under the technological category. India lacks the state-of-the-art wind resource assessment to establish wind farms, as the developers use data from the National Aeronautics and Space Administration (NASA) with 70–80% confidence level, National Renewable Energy Laboratory (NREL), or assign a task to external organizations to fetch on-ground data. Due to the inappropriate assessment of wind resources, the output of new wind farms is not up to the mark (Kumar et al. 2019). The lack of production facilities is also an influencing barrier within this group by receiving 0.0740 weight. All modern economies are expanding their production facilities to support the wind power sector. The world’s largest wind equipment manufacturers, like Vestas, Goldwind, GE Energy, Siemens Gamesa, and Nordex, belong to Denmark, China, the USA, Spain, and Germany (Irfan et al. 2019). In this regard, the share of Indian manufacturers is negligible in the global wind energy market.

Under the infrastructure category, land acquisition complexity is the highest-ranked barrier by obtaining a priority weight of 0.0612. Scholars stated that land acquisition for establishing wind farms is a long-awaiting process. Approval is also needed for this purpose from various government institutions. Several wind power schemes in India have been postponed due to land acquisition problems (Ota and Singh 2018). Inaccessibility to railways and highways obtained a priority weight of 0.0271 and is also a major impediment to the wind power sector. Due to ideal conditions for generating wind electricity, some wind projects have been established in remote regions of the country, which do not have access to rail and highways. In these situations, the transportation of rotor blades, wind turbines, and associated components to destination sites is always difficult (Jangid et al. 2016). In some cases, even the expensive wind equipment got damaged during transportation, which delayed the construction of wind farms (Kulkarni and Anil 2018).

The lack of a comprehensive wind power policy receives 0.0429 weight and is the top-ranked barrier within the policy and regulatory domain. Studies revealed that stakeholders continue to be discouraged by the lack of clarity around current and projected wind policies, infrastructure, and grid configurations (Kulkarni and Anil 2018). In recent decades, China has announced a variety of wind development plans. These plans are intended to optimize the structure of China’s energy industry and to meet emission reduction objectives through the growth of renewable energy sources such as wind energy. However, during the course of development, the chain of wind energy industries faces several barriers, one of which is the lack of a comprehensive wind power policy (C-B et al. 2015). Unbalanced FIT is also a crucial barrier under this domain, having 0.0259 weight. FIT has been specified in all states by the State Electricity Regulatory Commissions. However, based on cost-plus approach, an FIT does not allow the maximum consumption of wind energy.
Under the socio-cultural category, noise and visual impact is the top barrier with a priority weight of 0.215. Scholars have reported that these are the main concerns of people living near wind farms (Schäffer et al. 2019). The noise produced by Industrial Wind Turbines has detrimental health and sleep consequences. Similarly, most people think that the construction of a wind farm close to their residence is unappealing (Delicado et al. 2017). Adverse impact on wildlife and birds obtained a priority weight of 0.0114 under this category. Wind projects usually need constructing buildings, and related stuff on massive land, destroying the natural habitats of wildlife (Łopucki, Klich, and Gielarek 2017). Similarly, birds having low maneuverability frequently collide with rotor blades (Stokke et al. 2020).

The G-TOPSIS results reveal that the availability of adequate funds (0.371) is the best alternative to alleviate wind power barriers. In a developing country’s context, Ajayi (2010) assessed the issues of wind energy development and utilization in Nigeria. The authors opined that the initial capital cost for wind energy technology is very high compared to other conventional energy sources, if however, the governments would give subsidies to sales/purchases of wind energy technology, provided tax incentives or holidays to willing investors along with low or interest-free loans through banks, there would be rapid development of wind technology for power generation. Another study provided an overview of wind energy development programs from a Malaysian perspective (Ho 2016). The study concluded that fossil fuels are still heavily subsidized amid the subsidy reform in 2013, which is the major reason for the slow progress of wind energy in the country. In this respect, a strong political commitment to providing adequate funds and subsidies to the wind energy sector can boost wind energy development in the country. As a global leader in wind energy installations, China has introduced several attractive subsidies for wind manufacturing companies. China’s turbine industry is growing due to government support via different subsidies, increasing turbine demand from current and projected wind farms, and the availability of affordable raw materials. China is also the best place for turbine and component production, as the country is home to 15 of the world’s largest original equipment manufacturers. Chinese controlling shareholders that develop and industrialize the manufacturing of 1.5 MW and bigger wind turbines and components received a subsidy of CNY600/kW in 2008 for the first 50 turbines (Sahu 2018).

6. Conclusions

This study identifies and ranks wind energy development barriers in India based on their obstruction level and suggests alternatives to tackle them. A thorough literature review assisted in finding important barriers. Later, a panel of experts refined those barriers using the modified Delphi method. A total of 25 barriers were identified and grouped within five major dimensions, including technological, socio-cultural, financial, infrastructure, and policy and regulatory. Using the AHP approach, the weights of each of these barriers were then determined. The results reveal that the financial barrier having 0.494 weight is the top-priority barrier among major barriers. Technological barrier weighing 0.235 ranks second among this category. Similarly, the infrastructure barrier weighing 0.124 is the next crucial barrier, while policy and regulatory (0.099), and socio-cultural (0.049) are the least priority barriers. Among those, limited government subsidies, having a priority weight of 0.2519, are the top-ranked sub-barrier, while the unsatisfactory regulatory structure is the least influential, with a weight of 0.0035. Further contributions to the current pool of knowledge are extended using the G-TOPSIS application, helping with new findings by prioritizing the top four alternatives to wind energy development barriers. The G-TOPSIS results show that the availability of adequate funds is considered as the most effective alternative having a grayness degree of 0.371, followed by the development of infrastructure (0.522), reformations in the policy framework (0.531), and enhancing R&D activities (0.664), respectively. Finally, sensitivity analysis was performed to ensure the system’s robustness. The analysis specifies that study results are robust and stable; hence, appropriate for the decision-making process. Consumers, policymakers, and state organizations may now more rapidly implement
solutions that result from the integrated management of efficient approaches for attaining environmental sustainability.

7. Policy implications

7.1. Theoretical implications

AHP is a framework for problem-solving and a measurement theory. It is a decision analysis approach used to evaluate complicated alternatives among several experts. It is considered a progression over other decision-making methods because it includes subjective factors. The AHP has received global recognition due to its ability to assist experts in a wide variety of fields. Over the last few decades, research has focused on theoretical advances in AHP, fuzzy decision-making approaches, and explicit AHP applications to assist in management activities. This study combines AHP and G-TOPSIS, which contributes to the advancement of AHP’s integration with other multicriteria techniques for traditional and emerging decision-making concerns. Hybrid and robust methods are gaining importance at a breakneck pace. Those developing approaches are based on already established procedures, and their change via the use of fuzzy and gray theory will aid in their comprehension (Mardani et al. 2015). To assist practitioners and scholars intrigued by hybrid MCDM approaches, additional research and relevant studies on these methods should be published in the future. As demonstrated in this analysis, academics can generate critical criteria from the existing knowledge, expand on earlier work by incorporating knowledge from subject specialists, and advance the theory through the use of contemporary ways to decision analysis.

Along these lines, the findings of our work offer policymakers, researchers, and practitioners with important insights. The approaches employed in this study give a very effective way for decision-making. These approaches are applicable to resource distribution, project ranking, and assortment by practitioners, policymakers, and researchers. The approaches employed in this research enable the capturing of strategic objectives that can then be utilized to pick projects and inform stakeholders. Numerous industrial sectors have benefited from multi-criterion decision-making approaches. Due to their complexity, it is necessary to emphasize multidisciplinary and social decision-making challenges.

7.2. Managerial implications

Based on the study findings, the following managerial policy proposals have been put forward to successfully overcome the barriers hindering wind energy development:

- **Establish an innovative financial framework:** The most important financial barriers to wind energy development include limited government subsidy and the high initial cost of establishing new wind farms. Similarly, high duties on importing foreign equipment and the absence of a financial framework are other critical concerns. There is a limited share of foreign investment, as domestic wind power plants do not appeal to foreign investors. In this context, significant efforts by the concerned authorities are required to build an alternative financial structure to aid in the development of wind energy. The state should provide subsidies and support microfinance initiatives that provide low-interest loans. Wind energy facilities demand a substantial amount of resources to create and maintain. Reduced wind energy costs significantly increase investors’ interest and create a high rate of return. This may be accomplished through technological innovation and the development of wind farm models that are suited for the size, local conditions, and functional requirements.

- **Adopt technological advancements:** The country lacks slashing technologies and is dependent on external suppliers for critical components necessary for the development of megaprojects. The key roadblocks for the Indian wind sector will be technological advancements and compliance regulations. The wind industry must constantly adopt new norms and technical breakthroughs to
ensure long-term viability. Wind energy R&D is viewed as a major value-adding component of the industry. In this spirit, continual R&D efforts should be aimed toward the development of indigenous manufacturing facilities in order to decrease operational costs and reliance on foreign suppliers. To speed up the process, sufficient funds should be put aside. The effective use of wind energy requires a professional workforce to fulfill quality standards. Wind energy facilities are largely nonfunctional owing to a lack of quality control, which tarnishes the wind industry's brand and increases financial risk. The state should educate and train people to develop a qualified workforce, ensuring that wind facility development, management, and support adhere to relevant quality requirements.

- **Improve infrastructure:** The infrastructure of the Indian wind industry requires substantial development. Land purchase is time-consuming and needs approval from many government agencies. In addition, there is an absence of conviction in land acquisition. In this regard, the land purchase mechanism should be streamlined by lowering reliance on government agencies, eliminating bureaucratic requirements, and embracing transparent methods of land acquisition. To facilitate the transfer of wind equipment to target locations, suitable roadways should be created. To reduce T&D losses, the T&D network should be enhanced with proper management and monitoring tools. The findings further revealed that the old grid configuration of India only supports conventional (fossil fuel-based) energy generation sources. In this regard, a significant investment is needed to transform the current grid configuration to facilitate wind energy. The institutional framework should be established to offer wind-based after-sales services. The government institutions should ensure the participation of all sectors to enter into new wind energy markets.

- **Improve policy mechanism and coordination among institutions:** The success of wind energy growth is reliant on politics. Lack of accountability regarding political decisions creates a barrier to executing and achieving development objectives. As a result, devolving political power to low levels may alleviate this issue by bringing it closer to real-world settings. It may assist in creating a competitive climate for local governments to pursue green energy targets for political advantage, indirectly boosting local wind power facilities. Lack of coordination and decision-making are significant obstacles to the effectiveness of wind power schemes. Coordination amongst institutions can help ensure that these programs are implemented optimally. As a result, government entities should concentrate their efforts on developing the institutional framework for planning and implementing wind energy projects. This requires the development of a comprehensive state wind energy policy. Unbalanced FIT is also a major obstacle in wind energy development in the Indian subcontinent. State Electricity Regulatory Commissions has specified FIT in all Indian states. However, it does not allow the maximum use of wind energy due to the cost-plus approach. The government should tackle this serious concern to promote wind energy in the country. Similarly, the regulatory structure should be improved by streamlining the land acquisition approval process for wind farms and broadening the ownership of assets through mandated initial public offerings and small-investor allocations while supporting big foreign investors in the long run.

- **Increase awareness about wind energy benefits among masses:** The noise and visual impact from operating wind turbines receive considerable attention in the planning phase of a wind farm. In India, people lack enough knowledge and understanding of wind technology. Consequently, the marketing and promotion efforts should be directed to the successful diffusion of wind energy. This will have a favorable effect on public image and the adoption of wind energy. Meanwhile, the wind energy tariff should be reduced in order to make it competitive to conventional thermal energy. This will directly influence public perceptions regarding the adoption of wind energy. Meanwhile, the system should be corruption-free and transparent. Regulations should be developed in such a way that every wind energy program includes sufficient checks and balances. Bureaucracy power must be reduced and a suitable tax structure should be established, with
documentation that entrepreneurs should be awarded a tax vacation for creating wind power schemes and can avail accelerated depreciation.

Though the study has provided some novel contributions, perspectives for future research works are also critical. For instance, there are additional barriers, such as infrastructure deficiency, risk, liberty, and security, which subsequent academics can concentrate on their efforts in order to produce some intriguing outcomes. Additionally, data was gathered during the pandemic situation in the country. The pandemic may restrict results’ generalizability. Future research is urged to reexamine these barriers in the aftermath of a pandemic. Due to the fact that the model was established with the assistance of a Delphi group, there will be some variation among experts participated in the research. Modifications to the modeling process can be made to assist avoid this problem. An additional Delphi group can be employed in the future to modify and augment the model. Finally, the findings may be refined and expanded by employing other MCDM models and can be utilized in future works to compare and contrast results, gain new insights, and extend this study.

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