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Analyzing the factors influencing the wind energy adoption in Bangladesh: A pathway to sustainability for emerging economies

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ABSTRACT

The future of energy security has become a prominent concern for emerging economies due to the inevitable depletion of fossil fuels and the ongoing disruptions in their supply. The crippling effect of complete dependence on expensive fossil fuel imports is magnified by the ineffective policy response to the enduring energy crisis, impeding progress across various sectors and thwarting efforts to meet the demands of population growth and industrialization amid acute electricity shortages. Amidst the economic growth of a prominent emerging economy, Bangladesh, wind energy emerges as a transformative solution to effectively tackle the mounting challenges of electricity demand, environmental pollution, greenhouse gas emissions, and the depleting reserves of fossil fuels. Therefore, this study utilizes an integrated multi-criteria decision-making (MCDM) approach combining the inter-valued type 2 intuitionistic fuzzy (IVT2IF) theory with the decision-making trial and evaluation laboratory (DEMATEL) method aiming to identify, prioritize, and investigate the relationships among the factors that impact the sustainable adoption and growth of wind energy in an emerging economy like Bangladesh. Initially, the factors were derived from reviewing existing literature. After subsequent expert validation, sixteen factors were selected for analysis using the IVT2IF DEMATEL method. The findings of the study indicate that "Fossil fuel supply disruption," "Stable financial investment and resource mobilization," and "Geographical region" are the most significant factors influencing the adoption of wind energy for national grid support with prominence value 4.415, 4.406 and 4.339 respectively. Moreover, "Fossil fuel supply disruption" is also the most significant causal factor with a causal weight of 1.274, which is followed by "Stable financial investment and resource mobilization" and "Geographical region" with a causal weight of 1.029 and 0.794. The study's findings have the potential to aid decision-makers and policymakers in formulating long-term strategies and investment decisions to improve the sustainability of the national grid and achieve carbon neutrality.

1. Introduction

The energy demand is drastically rising as the world's population expands and economies progress [1]. The traditional energy sources, fossil fuels (coal, natural gas, and oil), are becoming increasingly costly and limited, and their consumption is leading to significant environmental issues, including air pollution, global warming, and climate change [1]. Fossil fuels, responsible for 61.3 % of global electricity in 2020, pose an immense sustainability challenge due to their contribution to greenhouse gas emissions [2]. With fossil fuels continuously depleting and environmental harm evolving, the world is accelerating toward an energy crisis, making sustainable energy solutions a more pressing need [3].

Therefore, decarbonizing energy systems worldwide is a significant challenge of utmost importance in the 21st century. The absence of decarbonized energy systems will have dire consequences, making their adoption essential, despite their complexity [4,5]. Moreover, the COVID-19 pandemic and the ongoing Russia-Ukraine conflict have sparked doubts about the dependability of non-renewable energy resources, necessitating policymakers to take urgent steps to reduce fossil

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fuel dependence for vulnerable importers [6]. Thus, the future hinges on transitioning toward a smart, sustainable energy system, which will be crucial to meeting the challenges of climate change and energy security [7].

As a key component of modern sustainable energy systems and the most rapidly expanding renewable electricity source, wind energy drives us toward a future fueled and supported by clean energy sources [8,9]. Harnessing wind energy is rapidly emerging as one of the most swiftly expanding energy sources worldwide. The elevated level of wind power's grid penetration is exerting a transformative influence on the operation of the modern grid system, heralding a new era of sustainable energy. Wind energy leverages wind turbines' power to create a compelling blend of environmental sustainability and economic viability [124].

The demand for energy on a global scale has soared considerably over time, with developing countries leading in this trend [10]. Bangladesh, a prominent developing country in South Asia, is progressing toward its next phase of progress. The quest for self-sufficiency in electricity production is crucial in meeting the escalating demand for electricity and advancing its status to that of a high-income country. The power industry in Bangladesh is heavily reliant on fossil fuels, with natural gas playing a dominant role in electricity generation, highlighting the urgent need for the country to transition towards cleaner, more sustainable energy sources [11]. Natural gas is the primary source of power generation, while coal, imported liquid fuel, and hydropower contribute to the remaining portion [8]. The energy mix scenario of Bangladesh is depicted in Fig. 1. Although natural gas constitutes the most significant proportion of Bangladesh's current energy mix, it is anticipated to be depleted by 2028 unless additional gas fields are identified [12]. Moreover, the absence of oil resources has resulted in the government of Bangladesh relying on imported diesel to fuel its diesel power plants, an inadequate approach to achieving energy self-sufficiency. The government is actively seeking diverse energy sources to generate power in response to the persistently increasing demand for electricity [13].

To promote sustainability and energy security, the Bangladeshi government has set targets of producing 40 % of its electricity from clean energy sources by 2041 [126]. Fig. 2 depicts Bangladesh's current renewable energy production scenario [14]. By 2030, the government of Bangladesh aims to generate 1370 MW of electricity through wind power [15]. Bangladesh holds enormous potential for wind energy generation, with wind speeds ranging from 5.75 to 7.75 m/s over an area of around 20,000 square kilometers, leading to the production of a staggering 30,000 MW of wind power, paving the way for a more sustainable and renewable future [16].

Despite Bangladesh's enormous potential in wind energy, the country has been sluggish so far in adopting this promising technology.

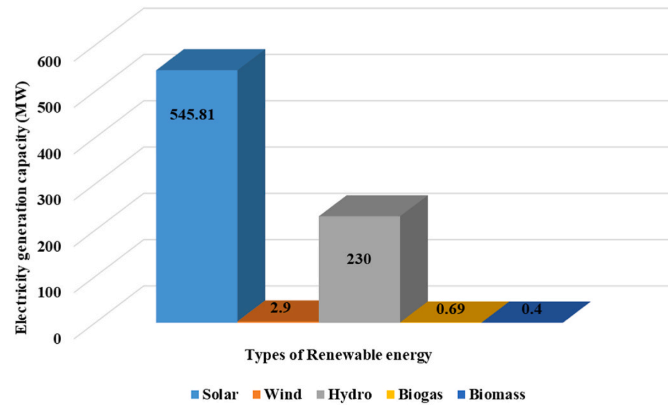

Fig. 2. Electricity generation capacity with different renewable energy in Bangladesh.

Furthermore, there is a noticeable absence of comprehensive research on the measures that drive the adoption of wind energy, particularly in an emerging economy context like Bangladesh. This gap in the existing literature is quite conspicuous and requires further exploration. Hence, this study aims to address the following crucial research questions (**RQs**):

RQ1. What are the major factors propelling the adoption of wind energy in developing nations?

RQ2. What is the relative importance of these driving factors, and how do they rank hierarchically?

RQ3. How are these factors interrelated, and can these interrelations contribute to developing the most effective policy interventions?

RQ4. How can adopting wind energy contribute to addressing the looming energy crisis in emerging economies and promote sustainability?

This study aims to address the abovementioned RQs by pursuing the following research objectives (**ROs**):

RO1. To identify the key factors influencing the adoption and growth of wind energy as a solution to the looming energy crisis in an emerging economy context.

RO2. To prioritize the identified factors and investigate their causal relationships in order to aid in formulating strategies for sustainable adoption and expansion of wind power.

RO3. To propose recommendations for policymakers, industry leaders, and other stakeholders to achieve a resilient, low-carbon energy

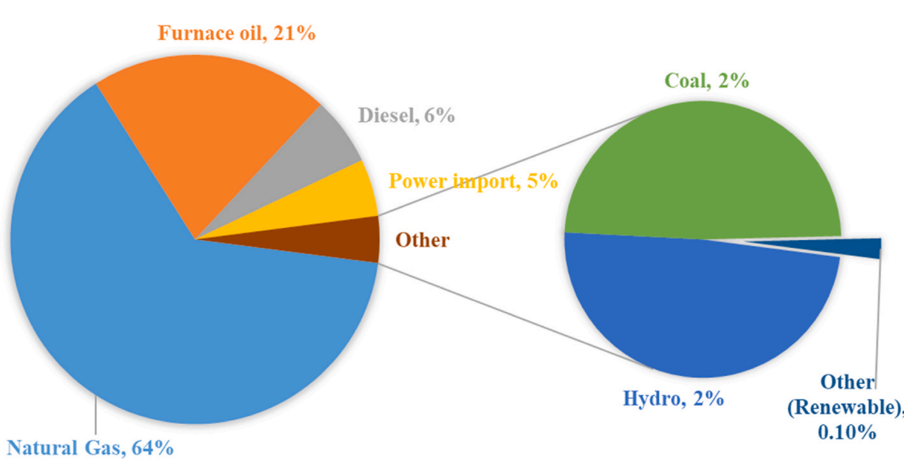

Fig. 1. Energy mix scenario of Bangladesh (Data extracted from [8].

system.

To accomplish the abovementioned ROs, this research deploys a structured multi-criteria decision-making (MCDM) approach integrating the inter-valued type-2 intuitionistic fuzzy (IVT2IF) theory with the decision-making trial and evaluation laboratory (DEMATEL) technique to evaluate the factors that facilitate the adoption and growth of wind energy in emerging economies like Bangladesh.

The DEMATEL method is a preferred MCDM approach for revealing the underlying cause-and-effect relationships between numerous factors, offering valuable insights into complex decision-making scenarios [17]; [125]. The DEMATEL approach offers various advantages over other prominent techniques such as ELECTRE, TOPSIS, AHP, ANP, and VIKOR [18]. DEMATEL visually illustrates causal links through impact-relationship mapping and quantifies interdependence between criteria, aiding complex problem analysis [18,19]. Additionally, DEMATEL determines element rankings, identifies key influencers, and assesses their weights [125]. Unlike ANP and AHP, which lack consideration for interrelationships and conditions among components, DEMATEL addresses these crucial aspects [20]. Furthermore, techniques such as interpretive structural modeling (ISM) are capable of evaluating direct influences between factors, but they are unable to analyze indirect correlations [17]. In this context, DEMATEL surpasses ISM, AHP, BWM, TOPSIS, and SWARA methods by recognizing comprehensive interconnections among factors, making it more effective [17]. Moreover, cognitive maps rely on a larger data set for modeling, whereas DEMATEL can effectively work with smaller sample data [21].

Combining the DEMATEL method with other theories (grey theory, rough set theory, fuzzy theory, Pythagorean theory, etc.) to address the uncertainty in the system is a common practice to evaluate potential factors across various systems [20,22,23]. This study combines the IVT2IF theory and DEMATEL to analyze the key driving factors of wind energy adoption in the context of the impending energy crisis. There are several compelling justifications to support the use of IVT2IF theory-based DEMATEL in this research. For instance, the proposed intuitionistic fuzzy theory is a suitable technique for handling uncertainty and vagueness by incorporating both the "degree of disagreement" and the "degree of agreement" [24]. It can enhance the effectiveness of decision-making processes. Again, by adjusting the level of hesitancy, the intuitionistic fuzzy sets (IFS) can better model the uncertain data that can arise when decision-makers are unsure about their preferences [25]. Hence, the proposed Interval Valued Type 2 Intuitionistic Fuzzy Numbers (IVT2IFN) introduced with DEMATEL can provide a more flexible model for elaborating uncertainty and vagueness [26]. Therefore, integrating IVT2IFN theory and DEMATEL can effectively handle the imprecise and uncertain aspects of human judgments, thus overcoming the limitations of the DEMATEL technique and enhancing the precision of the interrelationships among various factors.

The rest of the paper is structured as follows: Section 2 presents a brief literature review. Section 3 describes the study's methodological approach. The study results are presented in Section 4, and the findings are discussed in Section 5. Section 5 also highlights the study's theoretical, practical, and sustainable implications. Finally, section 6 concludes the study.

2. Literature review

2.1. Conceptualizing the factors contributing to the adoption of wind energy

Wind energy is a clean and renewable source of power that has the potential to play a significant role in mitigating climate change and promoting sustainable development in emerging economies' looming energy crisis contexts [27]. Compared to fossil fuels, wind energy has several advantages, including lower greenhouse gas emissions, reduced dependence on imported fuels, and the potential to create local jobs and economic development [28–30]. However, realizing the full potential of wind energy in an emerging economy requires understanding the drivers that shape its growth and adoption. This section aims to conceptualize the drivers of wind energy by reviewing the literature and exploring their relevance in Bangladesh, an emerging economy. Hence, we can gain insights into the factors that may be relevant for other emerging economies seeking to promote sustainable energy solutions and contribute to global sustainability efforts.

The government of Bangladesh has prioritized the expansion of wind power as a renewable energy source following the success of hydropower and solar power [15]. However, there is a lack of literature directly identifying the drivers of wind energy in Bangladesh. Therefore, we expanded our literature search to include other countries or economies with wind energy drivers compatible with Bangladesh's socioeconomic and geographic context. For instance Ref. [31], investigated the causal relationship between renewable energy investment, green finance, economic growth, renewable energy electricity output, and energy investment with private participation in China. They strongly recommended policies to address volatility and promote investment in these sectors for sustainable economic growth. Moreover [32], examined how the war between Ukraine and Russia had impacted European energy politics. The conflict has created uncertainty in energy affairs but also presented opportunities for reducing energy vulnerability and pursuing faster decarbonization by resource mobilization. Consistent with those studies, it can be argued that stable investment and resource mobilization for renewable energy can be an important driver for wind energy in emerging economies.

To promote the successful integration of wind energy and reduce the country's reliance on fossil fuels [33], examined the potential for small wind generation to contribute to the expansion of distributed power grids in Brazil. It is argued that promoting the small wind market in Brazil is a significant challenge; however, lessons learned from the United States, such as the net metering system or special tariff, could guide public policies to foster this technology and promote a low-carbon economy [34]. reviewed the latest policy framework for wind energy in Africa, focusing on Kenya, which has attracted significant wind energy investments. It suggested that supportive policies and fiscal incentives, such as feed-in tariffs (FIT), are essential for wind energy development and gaining international private participation.

Moreover, Li et al. (2020) emphasized the importance of commercialization for promoting wind energy while recommending choosing different hub heights for wind turbine installations at the onshore and offshore sites for economic feasibility and optimal annual energy production. These findings could be significant for upcoming coastal wind energy projects in Bangladesh. For instance, Washim Akram et al. (2022) highlighted the prospect of wind energy in the country's coastal location to alleviate energy needs, particularly in rural areas. Similarly [10,30], showed that the country's 574 km long coastline, with a steady wind speed of almost 7 m/s, is a geographical driving factor for wind energy utilization. The wind resource map of Bangladesh shown in Fig. 3 (this figure has been contracted using the data extracted from https://www.re-explorer.org/re-data-explorer/on 10 June 2023) also indicates the high possibility of wind energy, especially around coastal regions.

Excessive land requirements, particularly for solar and hydroelectric projects, emerge as a significant barrier to utilizing renewable energy in an emerging economy [4]. However, a study by Adnan et al. (2021) showed the feasibility of wind resource assessment in Pakistan. It concluded that wind farms have high energy potential and low energy cost regarding land utilization and compatibility with agricultural activities, making them suitable for sustainable energy production. In contrast to other renewable energy sources, for densely populated countries like Bangladesh, the compatibility of wind energy with agricultural activities and the efficient use of land can drive its development. Again, to establish renewable energy [35], investigated the acceptance or rejection of renewable energy sources in Greece by examining residents' attitudes toward their development. The study found that

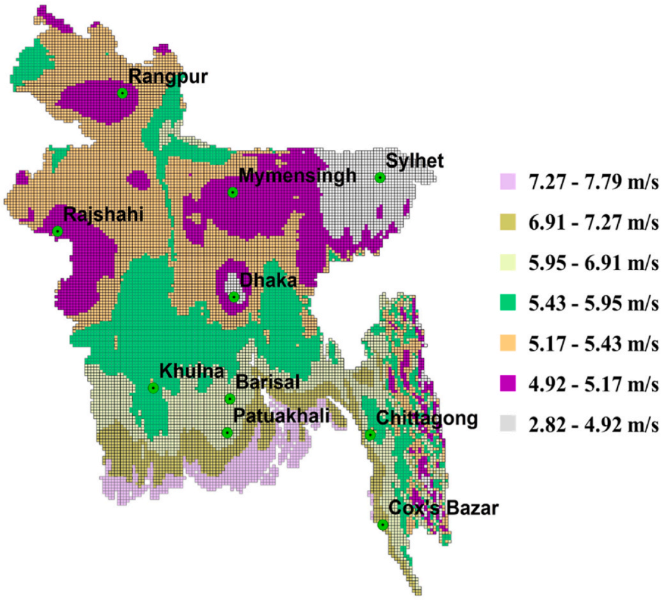

Fig. 3. Wind resource in Bangladesh at 100 m height.

although most participants favor renewable energy development, they do not want such projects located near their residences and are not willing to contribute financially to their development. So, social acceptability drives the adoption of renewable energy sources like wind.

However, Fossil fuel-based energy sources exacerbate the problems concerning climate change [36]. Renewable energy sources have the potential to decarbonize the electricity industry by 90 % by 2050, contributing to climate change mitigation and limiting global temperature rise [37]. [38] specifically discussed the potential of wind energy to replace conventional fossil fuels to address environmental concerns, focusing on Pakistan. The studies indicated that reducing negative environmental footprint drives wind energy development significantly. Therefore, Murshed et al. (2022) analyzed the impact of various factors on carbon productivity in emerging countries, finding that improving energy use efficiency and increasing renewable energy use can positively impact carbon productivity. Meanwhile [39], found that income growth positively affects renewable energy consumption in Bangladesh, which has been growing since 1990. So, wind energy development for tackling urbanization-driven energy demand surge in this context can influence energy sustainability in the country.

After an extensive literature review, an initial list of seventeen factors influencing the adoption of wind energy to support the national grid has been developed, which is provided in Appendix A of the supplementary materials. This initial list was then presented to the experts in the form of a survey to collect their feedback on their relevance. The experts removed two factors ('Development of appropriate energy storage technological infrastructure' and 'Developing green infrastructure in power generation') and added one more factor ('Improved energy efficiency'). Thus, a total of sixteen factors have been obtained finally, based on expert feedback and the literature review, which is shown in Table 1.

2.2. Research gap and study contribution

Wind energy has been celebrated as a powerful alternative source of power in advanced economies, contributing significantly to achieving carbon neutrality and sustainability goals through reductions in greenhouse gas emissions, enhancement of energy security, and support for national grids [51–53]. However, the adoption of wind energy has been relatively slow in many emerging economies, especially in regions where the potential for wind power is vast but yet to be fully harnessed,

Table 1
Finalized factors influencing the adoption of wind energy.

Code	Factors	How does the factor influence the adoption of wind energy?	Source
F1	Geographical region	The geographical landscape of a region affects higher wind speeds and consistent wind patterns, which are more suitable for generating electricity. However, mountains, valleys, and urban structures can disrupt or channel wind, influencing the efficiency of wind turbines.	Washim Akram et al. (2022) [10, 30];
F2	Continuous support and involvement from regulating authorities	Regulatory bodies can influence and shape wind energy's development, deployment, and growth by implementing clear, stable, and long-term regulations to create a conducive environment for its adoption.	Hussain et al. (2022)
F3	Promoting the commercialization of renewable energy	Commercialization promotes wind energy to become more accessible to a broader range of consumers, including businesses, utilities, and individual homeowners, which increases accessibility and encourages wider adoption of wind energy.	[40]
F4	Social acceptability and adaptability	The level of support and willingness of local communities, stakeholders, and the general public are essential to address concerns, gather feedback, and build trust for embracing wind energy projects. This can significantly impact wind energy projects' success and growth.	[35]
F5	Fossil fuel supply disruption	Fossil fuel supply disruptions can result in price spikes and increased volatility, leading to higher energy costs for consumers and businesses, prompting stakeholders to explore more stable and predictable alternatives, such as wind energy. Thus, fossil fuel supply disruptions often catalyze increased interest and investment in wind energy.	[41]
F6	Reduced negative environmental footprint	Wind energy is often considered a more environmentally friendly alternative to fossil fuels due to its lower emissions, reduced impact on ecosystems, and sustainable resource availability, and has a lower impact on biodiversity and ecosystems compared to fossil fuel-based alternatives.	[37,38]

(*continued on next page*)

Table 1 (*continued*)

Code	Factors	How does the factor influence the adoption of wind energy?	Source
F7	Tackling urbanization-driven energy demand surge	Wind energy offers a clean, accessible, and renewable source of electricity, helping to meet the growing energy consumption in urban areas associated with the growth and expansion of cities.	[39,42]
F8	Integration of feed-in tariff (FIT) and net metering system into the energy infrastructure	Both mechanisms provide financial incentives and facilitate the integration of renewable energy sources like wind into the energy mix. The revenue certainty offers a stable income stream for wind energy project developers and consumers, making investments, saving bills, and reducing financial risks.	[33,34]
F9	Stable financial investment and resource mobilization	Stable financial investment and resource mobilization provide the necessary capital and resources for the development, feasibility studies, site assessments, permitting, and operation of wind energy projects.	[31,32]
F10	Land utilization and compatibility with agricultural activities	The successful integration of wind energy projects into agricultural landscapes requires careful consideration of land use, environmental impacts, and the coexistence of farming activities, such as crop cultivation or grazing.	Adnan et al. (2021)
F11	Maximizing cost efficiency potential	Maximizing cost efficiency improves the return on investment (ROI) for wind energy projects, making them more attractive to investors. As with any energy source, the cost competitiveness of wind energy plays a significant role in determining its attractiveness to investors, utilities, governments, and consumers.	[43,44]
F12	Improved energy efficiency	Improved energy efficiency helps stabilize the electricity grid by reducing peak demand and the risk of power outages. This enhances the grid's ability to accommodate variable energy sources like wind by providing a more flexible and stable platform for integration.	Expert Feedback
F13	Affordable means to ensure energy supply security	Wind energy adds diversity to the energy mix, reducing dependence on a single energy source (e.g., fossil fuel-based sources) and enhancing overall energy supply security. Wind energy can act as a stable and reliable alternative in supply disruptions or price volatility in conventional energy markets.	[45]
F14	Minimal and economical maintenance	Wind energy projects with minimal and economical maintenance requirements result in lower operating costs over the project's lifetime.	[46]
F15	Potential capacity mix integration	Wind energy provides diversification in the energy generation mix by offering a renewable and variable source of electricity. This diversification reduces dependence on a single energy source and enhances energy supply security.	[47,48]
F16	Auspicious governmental initiatives and fiscal policies	Governmental initiatives, such as feed-in tariffs, production tax credits, investment tax credits, and subsidies, provide financial incentives that make wind energy projects more economically viable and attractive to investors.	[49,50]

perhaps due to inadequate integration with the national grid infrastructure or lack of understanding of the benefits [54,55]. Nevertheless, deploying wind energy in these emerging economies is essential as they grapple with the dual challenges of balancing economic growth with environmental stewardship [56]. These nations often face the problem of accelerating development while keeping their carbon footprint minimal and energy supply security. However, the existing models do not effectively address the complex factors contributing to the successful integration of wind energy, thus calling for a comprehensive analysis to fill this gap.

Some researchers have examined the aspects of wind energy from various perspectives. For instance Ref. [51], discussed the role of wind energy in achieving SDGs, using the London Array wind farm as an example. They emphasized the importance of clean energy in reducing emissions and supporting SDGs. The study proposed 77 indicators to align the project with various goals: employment, infrastructure, sustainability, and biodiversity. However, it is important to note that the study's focus on the specific case of the London Array wind farm may limit its generalizability to other wind energy projects. Additionally, the reliance on proposed indicators without a comprehensive evaluation of their effectiveness in achieving the SDGs is a limitation of the descriptive study. Again, Govindan (2023) focused on the functional and technical barriers to implementing offshore wind energy in India's low-carbon energy transition using the DEMATEL method. However, the study did not emphasize the drivers of wind energy, posing a significant area to explore.

[57] developed a framework to identify and categorize offshore wind energy barriers in India using fuzzy AHP, prioritizing technical and financial barriers as the most significant [58]. focused on Turkey's renewable energy potential and the establishment of wind power plants using Geographic Information System (GIS) and fuzzy AHP. However, these studies did not focus on the driving factors of wind energy. Furthermore, AHP, as an MCDM tool, is outweighed by DEMATEL due to its failure to show interrelationships among factors, which is a major advantage of DEMATEL over other MCDM techniques [125]; [59]. examined wind energy consumption drivers in 17 major countries using the logarithmic mean Divisia index (LMDI) method. The study emphasized the significance of energy policies that promote the transition to renewable sources for future increases in wind energy consumption. However, the research is limited by its focus on specific countries,

particularly some developed countries in Europe, and the use of a simplified methodology and limited data availability.

Different MCDM techniques, such as interval type-2 fuzzy sets, fuzzy AHP, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Combinative Distance-based Assessment (CODAS), and others, have been implemented in numerous studies for selecting the best site for wind power plants [60–64]. However, those studies pose a significant gap in analyzing the factors that can drive an emerging economy to adopt wind energy into the existing infrastructure.

Amid this situation, despite considerable research, there has been no significant investigation into identifying, prioritizing, and evaluating the driving factors influencing wind energy adoption in the context of national grid support, especially from the viewpoint of carbon neutrality and sustainability in emerging economies. Moreover, the interval-valued type-2 IF DEMATEL method used in this study exhibits more robust results for making decisions in ambiguous situations, simultaneously deriving both prioritization and causal relationships. Therefore, the contributions of this study can be summarized as follows:

Theoretical contributions

- Establishing a linkage among wind energy adoption, emerging economy, and achieving sustainability and carbon neutrality, especially in the energy sector.
- Evaluating and ranking these factors using the inter-valued type 2 intuitionistic fuzzy (IVT2IF) DEMATEL technique and determining the causal relationships.
- Providing a theoretical basis for successful wind energy adoption to promote sustainability in the energy sector of emerging economies.

Practical Contributions

- Identifying the key driving factors that significantly influence the adoption of wind to support the national grid.
- Guiding policymakers, energy sector leaders, and stakeholders in making strategic and operational decisions at various levels to facilitate the adoption and diffusion of wind energy.

Furthermore, this study discusses the theoretical implications and the impacts related to sustainability goals for effectively integrating and implementing wind energy in the context examined (see section 5.1-5.3).

3. Methodology

3.1. Survey design and data collection

In this research, the survey work has been conducted in two phases. Firstly, the factors contributing to adopting wind energy to support the national grid for carbon neutrality and sustainability have been identified from existing literature using the snowballing technique [22,65]. The factors have been searched in Scopus and Google Scholar databases with a timeline of 2015–2023. A research protocol was developed throughout the literature review, including searching databases, inclusion and exclusion criteria, key phrases, and research timeline, as shown in Table 2. More than 120 papers with key phrases were initially identified in this comprehensive literature review. However, following a rigorous full-text screening and utilization of the study protocol, only the 45 most relevant articles, projects, and reports were finally reviewed to address the specific RQs.

Therefore, following the research protocol mentioned above, 17 driving factors were identified initially for wind energy adoption in emerging economies. Table A1 of **Appendix A** in the supplementary materials provides this initial list of factors from literature resources, which was later sent to the experts for validation. In any variant of the DEMATEL method, it is possible to obtain reliable results if the number of participating experts is at least more than ten [125]; [66,67]. In this research, responses were gathered from 12 experts for validation, and the finalized list contained 16 factors, as provided in Table 1. The purposive sampling technique was applied to choose this study's decision experts (DEs) [68–70]. The purposeful sampling method is suitable for selecting experts for a particular assessment to achieve the study goal [71,72]. Fig. 4 illustrates the framework followed in this study.

Table 2
Applied research protocol for the systematic review of the literature.

Protocol Applied	Brief description
Databases	Google Scholar, Scopus, and Web of Science
Timeline	2015 to 2023
Language	English
Search Keywords	“Factors” OR “Success factors” AND “wind energy” OR “wind Power” OR “Renewable energy” OR "Drivers and of wind energy" OR “Factors influencing wind energy adoption,” etc.
Inclusion criteria	(i) Articles or scientific reports focusing on the potential, factors, or impact of wind energy; (ii) Articles addressing the ROs and RQs
Exclusion criteria	(i) Research articles that are not indexed in Scopus or Web of Science, or Google Scholar; (ii) Articles published in any language other than English; (iii) Articles that fail to address the specific RQs or research design ineffective; (iv) Articles that lack sufficient information and methodological rigor;
Data extraction	The selected factors were significant to sustainable wind energy adoption to support the national grid from an emerging economy perspective.

The study's framework (see Fig. 4) starts by clearly defining its research goal of systematically analyzing the factors influencing the adoption of wind energy, specifically focusing on its role in bolstering the national grid to achieve enhanced energy security and resilience. This analytical approach involves several distinct steps. The first step includes the identification of relevant factors. In this step, an extensive literature review is conducted to initially identify the factors contributing to wind energy adoption. These initially identified factors are then subjected to a validation process through expert consultation, utilizing a structured questionnaire to assess their relevance. After this validation phase, the list of factors is finalized, and later, a meticulously designed survey questionnaire is developed for subsequent in-depth examination of these finalized factors. In the second step, the factors are analyzed with a novel IVT2IF DEMATEL approach, utilizing the feedback from the experts. The feedback is collected through the questionnaire distribution. This step starts with collecting the feedback of DE through a structured questionnaire and semi-structured interview (see Table 1). After that, the IVT2IF DEMATEL was applied, resulting in the hierarchical ranking, clustering, and exploring causal relationships among the factors. The detailed procedure of the IVT2IF DEMATEL application has been described in subsection 3.4. In the final step, the findings from the analysis were validated with the experts. Then, after validation, the result was finalized and discussed along with the study's implications.

All DEs professionally belong to the energy sector; having expertise of at least six years in the relevant energy sector is the inclusion criteria for selecting DE. All the feedback was collected physically with a face-to-face interview. Initially, we approached 16 experts working in the energy area for this study. However, 12 experts (75 %) agreed to participate in the survey (both in factor validation and factor analysis). Table 3 shows the overall profile of the 12 respondent experts.

3.2. IFS and IVT2IF theory

The Fuzzy Set Theory (FST) was developed to cope with vagueness and uncertainty in information analysis [73,74]. It is defined by a non-membership function, a membership function, and a hesitancy degree reflecting neutrality, support, and opposition in expressing information [122]. Although IFS is a version of FST, the key distinction between the IFS and FST is that IFS can better manage the expert's

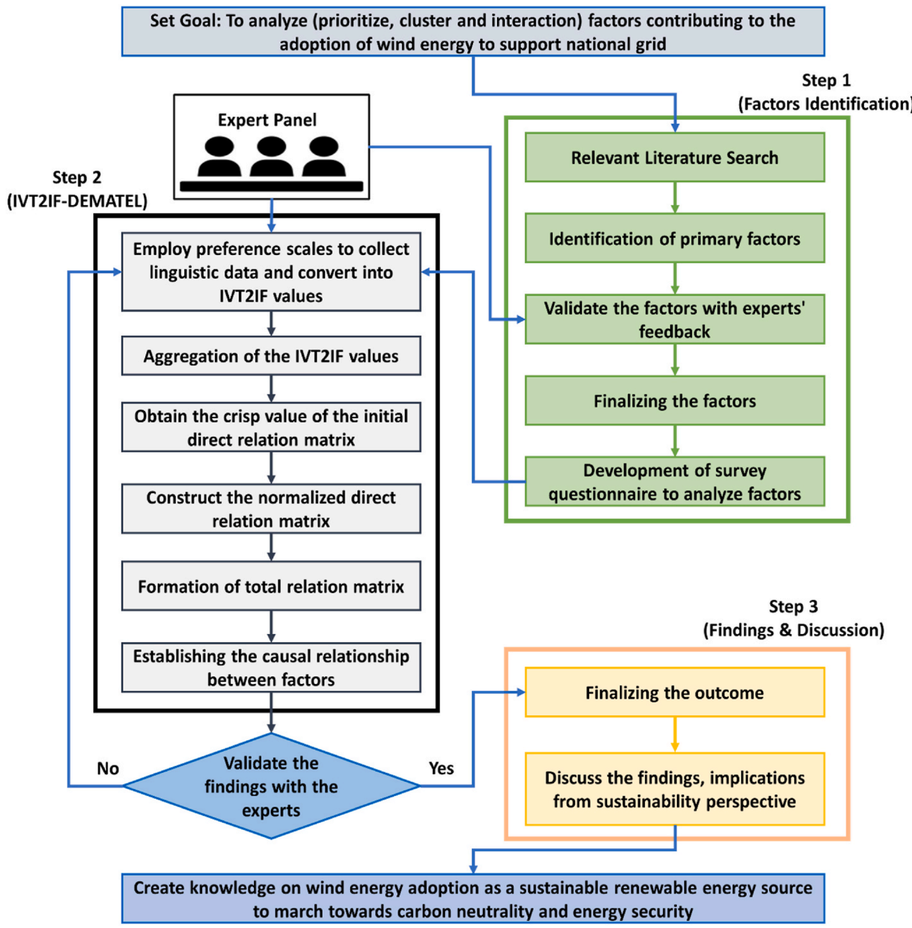

Fig. 4. Proposed methodological framework of the study.

vagueness [75]. Moreover, the IFS theory can represent unknown and uncertain data [76]. When decision-makers are unsure about their opinions, the IFS theory outperforms FST. Moreover, IFS can represent three membership functions: membership, non-membership, and hesitation. Type-1 fuzzy systems have a fixed membership function, whereas type-2 fuzzy systems have a fluctuating membership function. Although all fuzzy numbers reflect only one membership grade, it provides a crisp number in the interval [0,1] [77]. However, Type-2 fuzzy numbers enable the degrees of uncertainty that classical type-1 fuzzy numbers cannot. Compared to type-1 fuzzy sets, this extra dimension provides Type-2 fuzzy numbers with more degrees of freedom to better represent uncertainty [78]. The following section introduces the basic concept related to IVT2IF:

Definition 1. [79]. Suppose M is a finite, non-empty set, and W is a standard fuzzy set when $\alpha_W(m)$ is a membership function, when $\alpha_W(m) : M \rightarrow [0,1]$

Let, $R \subseteq M$ and $R = \{m, \alpha_W(m) : m \in M, \alpha_W\ (m)\ [0,1]\}$, while $\alpha_W(m)$, is denoted as the membership function of m in the W standard set.

Definition 2. [80]. The IFS in M can be denoted as

$$W = \{m, \alpha W(m), \beta W(m) : m\hat{I}W\}, \text{Where} W \text{is the fixed set} \tag{1}$$

In **Equation (1)**, $0 \leq \alpha_W(m) + \beta_W(m) \leq 1$ is considered for expressing $\alpha_W(m) : M \rightarrow [0,1]$ and $\beta_W(m) : M \rightarrow [0,1]$. Mainly, the membership degree of knowledge lacking is denoted as $\alpha_W(m)$ and the non-membership degree of the element is denoted as $\beta_W(m)$, for $m \in M$ to the fixed set W.

$$\Upsilon \text{W(m)} = 1 - \alpha \text{W(M)} - \beta \text{W(M)}, \text{Where} 0 \leq \alpha W(M) \leq 1 \tag{2}$$

Definition 3. [123]; [81]. An IVIFS W in M is denoted by $\widetilde{W} = \{\langle m, \widetilde{\alpha}_{\tilde{W}}(m), \widetilde{\beta}_{\tilde{W}}(m), \widetilde{\Upsilon}_{\tilde{W}}(m)\rangle | m \in M\}$, where $\widetilde{\alpha}_{\tilde{W}}(m) \subset [0,1]$, $\widetilde{\beta}_{\tilde{W}}(m) \subset [0,1]$, $\widetilde{\Upsilon}_{\tilde{W}}(m) \subset [0,1]$ are intervals, representing the degree of membership, non-membership, and hesitation, respectively, of element m in set W. Therefore, $\Upsilon^L_{\tilde{W}}(m) = 1 - \alpha^U_{\tilde{W}}(m) - \beta^U_{\tilde{W}}(m)$, $\Upsilon^U_{\tilde{W}}(m) = 1 - \alpha^L_{\tilde{W}}(m) - \beta^L_{\tilde{W}}(m)$ for $m \in M$.

Definition 4. [82]. Let $\widetilde{p}_i = ([\alpha_i^-, \alpha_i^+], [\beta_i^-, \beta_i^+])$ $(i = 1, 2, \ldots., n)$ is a collection of IVT2IFNs and $(w = w_1, w_2, \ldots., w_n)^T$, is the weight vector of $\widetilde{p}_i (i = 1, 2, \ldots., n)$, with $\sum_{i=1}^n w_i = 1$, then the interval-valued type 2 Intuitionistic fuzzy weighted geometric (IVT2IFWG) operator is a mapping IVPFWG : $\widetilde{P^n} \rightarrow \widetilde{P}$, where

$$IVT2IFWG(\widetilde{p}_1, \widetilde{p}_2, \ldots..\widetilde{p}_n) = \left(\left[\prod_{i=1}^n (\alpha_i^-)^{w_i}, \prod_{i=1}^n (\alpha_i^+)^{w_i} \right], \left[\prod_{i=1}^n (\beta_i^-)^{w_i}, \prod_{i=1}^n (\beta_i^+)^{w_i} \right] \right) \tag{3}$$

Table 3
Overview of the Expert's profile.

Experts	Educational Background	Designation	Organization type	Experience (years)
1	Ph.D. in Mechanical Engineering	Assistant professor	University	11
2	B.Sc. in Electrical Engineering	Electrical engineer	Power generation company	10
3	B.Sc. in Mechanical Engineering	Energy consultants	Private organization	15
4	M.Sc. in Mechanical Engineering	Energy expert	Government research institute	8
5	M.Sc. in Mechanical Engineering	Energy regulatory commission member	Government policy-making institution	12
6	Ph.D. in Mechanical Engineering	Postdoctoral scholar	University	16
7	B.Sc. in Electrical Engineering	Private contractors	Power generation company	14
8	B.Sc. in Mechanical Engineering	Mechanical engineer	Private R&D organization	7
9	M.Sc. in Mechanical Engineering	Researcher	Government research center	6
10	Ph.D. in Mechanical Engineering	Professor	University	18
11	M.Sc. in Industrial Engineering	Power plant manager	Power generation company	9
12	B.Sc. in Electrical Engineering	Electrical engineer	Private R&D organization	6

Definition 5. [83]. The linguistic term is defuzzified with Equation (4) from the fuzzy numbers α and β. Therefore, α_U and α_L are, respectively, the upper and lower values of fuzzy number α. Similarly, β_U and β_L are the upper and lower values of fuzzy number β, respectively. Thus, the crisp value is obtained from the linguistic term.

$$P = \frac{\alpha_L + \alpha_U + \sqrt{1-\beta_L^2} + \sqrt{1-\beta_U^2}}{4} + \frac{\alpha_L\alpha_U - \sqrt{\sqrt{1-\beta_L^2}\sqrt{1-\beta_U^2}}}{4} \tag{4}$$

3.3. DEMATEL method

DEMATEL is a decision-making method with a graph-theoretical approach that uses a cause-and-effect relationship between a set of factors [75]. Vertices illustrate the elements of a system, and edges present their cause-and-effect relationship. The method shows the co-relationship among the factors and predicts the factor's significance [84]. The DEMATEL findings can assist policymakers in understanding the degree of influence of various factors on particular scenarios. The fundamental steps of DEMATEL are as follows:

Step 1. Let there be F number of elements for pairwise comparison. For this purpose, the Direct-Relation Matrix (DRM) is constructed. An expert group of consisting N members developed the pairwise comparison from the experts' feedback. The DRM for the zth expert is followed by $X^z = (x_{ij}^z)_{F\times F}$ where, x_{ij}, is the influence of the factor F_i on the factor F_j.

The aggregate DRM, $X, \forall X^z$ where $z = 1, 2, \ldots\ldots, N$ and $£_z \in R$ is considered to be the significance of z^{th} expert. Therefore, X can be expressed as follows:

$$X = (x_{ij})_{F\times F} = \left(\frac{\sum_{z=1}^{N} £_z x_{ij}^z}{\sum_{z=1}^{N} £_z} \right)_{F\times F} \tag{5}$$

Step 2. Normalization of aggregate DRM, following Equation (6) and **(7).**

$$G = h^{-1}X \tag{6}$$

$$h = max\left(\max_{1\le i\le F} \sum_{j=1}^{F} x_{ij}, \max_{1\le j\le F} \sum_{i=1}^{F} x_{ij} \right) \tag{7}$$

Step 3. The Total Relation Matrix (TRM), T, can be illustrated by Equation (8) and calculated through Equation (9). T mainly previews the influential relationship among all factors.

$$\left(T = [t_{ij}]_{F\times F}\right) \tag{8}$$

$$T = G + G^2 + G^3 + G^4 + G^5 + \ldots.. = \sum_{i=1}^{\infty} G^i = G(I-G)^{-1} \tag{9}$$

here, t_{ij}, is the element of T in the i^{th} row and j^{th} column, respectively, and I is the $F \times F$ identity matrix.

Step 4. The factors are categorized into cause-and-effect groups. The summation of columns and rows is identified by D_i and R_j, respectively. The cause-and-effect graph is generated by mapping the numerical value of $(D_i + R_j, D_i - R_j)$

$$D_i = \left(\sum_{j=1}^{n} t_{ij} \right)_{F\times 1} = [t_i]_{F\times 1} \tag{10}$$

$$R_j = \left(\sum_{i=1}^{n} t_{ij} \right)_{1\times F} = [t_j]_{1\times F} \tag{11}$$

Step 5. The "Prominence Vector" is expressed as $(D_i + R_j)$, for comparing the significance of each factor. The "Relation Vector" is expressed as $(D_i - R_j)$, which classified into the cause group when $t_i - t_j > 0$; $i = j$ and effect group when $t_i - t_j < 0$; $i = j$.

3.4. *Interval valued Type 2 intuitionistic fuzzy DEMATEL (IVT2IF -DEMATEL) method*

Step 6. Define the contributing factor of wind energy adoption to support the national grid

The factors of wind energy are determined through semi-structured interviews followed by iterative and deductive procedures. The finalized factors are included in Table 1, along with their corresponding codes.

Step 7. Employ new preference scales to collect linguistic data

Table 4
Linguistic scale of IVT2IF for evaluating the factors.

Linguistic	Abbreviation	IVT2IF
No influence	N	([0.060, 0.260], [0.700, 0.900])
Very low influence	VL	([0.220, 0.420], [0.540, 0.740])
Low influence	L	([0.380, 0.580], [0.380, 0.580])
High influence	H	([0.540, 0.740], [0.220, 0.200])
Very high influence	VH	([0.700, 0.900], [0.060, 0.260])

The DM's judgments are collected by rating the factors on the linguistic scale and substituted with corresponding IVT2IF numbers. The linguistic scale and IVT2IF values [83,85] are shown in Table 4.

Step 8. Aggregation of the IVT2IF values

The IVT2IF values are aggregated with **Equation (5)** from **Definition 4**. The aggregated values are shown in Table B1 in **Appendix B** of the supplementary material.

Step 9. Obtain the crisp value of the initial DRM

The aggregated values are transformed into crisp values of the DRM through the defuzzified process using **Equation (4)**. The crisp values of DRM are presented in Table B2 in **Appendix B** of the supplementary material.

Step 10. Construct the normalized DRM

The initial DRM is normalized using **Equation (6)** and **(7)**. Each element of the initial DRM is divided by 9.414 as it is the maximum value of the total row and column (Table B2). Table B3 in **Appendix B** of the supplementary material shows the normalized DRM result.

Step 11. Construct the TRM

The TRM is constructed from the normalized DRM with **Equation (9)**, and the TRM is illustrated in Table B4, Appendix B of the supplementary material. The D_i and R_j Values are calculated with **Equation (10)** and **(11)** to obtain the $(D_i + R_j)$ and $(D_i - R_j)$, values. The cause group and effect group are categorized by $(D_i + R_j, D_i - R_j)$, in Tables 5 and 6, respectively.

Step 12. Establishing a causal relationship diagram

A threshold value (ϕ) is needed to avoid the comparable negligence effect of the experts, DMs, and analysts. The threshold value (ϕ) is the summation of the standard deviation and mean for TRM, T. When $T_{ij} > \phi$, then the contributing factor i influences the factor j. A directed arrow is embodied in the causal relationship diagram, which is plotted from the $(D_i + R_j, D_i - R_j)$, data set. The mean of T is calculated to be 0.121, and the standard deviation is 0.03459, resulting in $\phi = 0.155$.

4. Result

The prominence ranking of the influencing factors to develop sustainable wind energy has been shown in Table 5. The ranking of the factors is determined based on the influence level (D + R) as F5 (4.415) > F9 (4.406) > F1 (4.339) > F2 (4.223) > F7 (4.053) > F3 (4.005) > F16 (3.969) > F8 (3.969) > F12 (3.850) > F10 (3.741) > F14 (3.740) > F15 (3.642) > F6 (3.463) > F4 (3.442) > F11 (3.416) > F13 (3.202).

Table 5
Prominence ranking of the contributing factors adopting sustainable wind energy.

Code	Factors	D + R	Prominence Ranking
F5	Fossil fuel supply disruption	4.415	1
F9	Stable financial investment and resource mobilization	4.406	2
F1	Geographical region	4.339	3
F2	Continuous support and involvement from regulating authorities	4.223	4
F7	Tackling urbanization-driven energy demand surge	4.053	5
F3	Promoting the commercialization of renewable energy	4.005	6
F16	Auspicious governmental initiatives and fiscal policies	3.969	7
F8	Integration of feed-in tariff (FIT) and net metering system into the energy infrastructure	3.943	8
F12	Improved energy efficiency	3.850	9
F10	Land utilization and compatibility with agricultural activities	3.741	10
F14	Minimal and economical maintenance	3.740	11
F15	Potential capacity mix integration	3.642	12
F6	Reduced negative environmental footprint	3.463	13
F4	Social acceptability and adaptability	3.442	14
F11	Maximizing cost efficiency potential	3.416	15
F13	Affordable means to ensure energy supply security	3.202	16

Table 6
Causal ranking of the influencing factors for adopting sustainable wind energy.

Code	Factors	D-R	Causal Ranking	Group
F5	Fossil fuel supply disruption	1.274	1	Cause
F9	Stable financial investment and resource mobilization	1.029	2	
F1	Geographical region	0.794	3	
F16	Auspicious governmental initiatives and fiscal policies	0.367	4	
F14	Minimal and economical maintenance	0.141	5	
F3	Promoting the commercialization of renewable energy	0.111	6	
F11	Maximizing cost efficiency potential	0.074	7	
F10	Land utilization and compatibility with agricultural activities	−0.129	1	Effect
F7	Tackling urbanization-driven energy demand surge	−0.166	2	
F15	Potential capacity mix integration	−0.256	3	
F6	Reduced negative environmental footprint	−0.300	4	
F8	Integration of feed-in tariff (FIT) and net metering system into the energy infrastructure	−0.361	5	
F2	Continuous support and involvement from regulating authorities	−0.492	6	
F13	Affordable means to ensure energy supply security	−0.511	7	
F4	Social acceptability and adaptability	−0.696	8	
F12	Improved energy efficiency	−0.878	9	

The causal ranking of the influencing factors is presented in Table 6. The factors are classified into two groups: one is the cause group, and another is the effect group. Among the 16 factors, seven factors are established as causal factors (with D-R > 0), and nine factors are established as effect groups (with D-R < 0). The factors of the cause group are ranked as F5 (1.274) > F9 (1.029) > F1 (0.794) > F16 (0.367) > F14 (0.141) > F3 (0.111) > F11 (0.074). The factors of the effect group are ranked as F10 (−0.129) > F7 (−0.166) > F15 (−0.256) > F6 (−0.300) > F8 (−0.361) > F2 (0.492) > F13 (−0.511) > F4 (−0.696) > F12 (−0.878).

The cause-and-effect diagram of the factors generated by Tables 5 and 6 is shown in Fig. 5. The cause-and-effect diagram was drawn, keeping D-R in the Y-axis and D + R in the X-axis on the Cartesian Plane. The factors are classified into driving factors (V1), independent factors (V2), critical factors (V3), and impact factors (V4). The cause group includes the driving factors (V1) and critical factors (V3). Similarly, both the impact factors (V4) and independent factors (V2) belong to the effect group. The critical factors (V3) are the most influencing factors as V3 inheres in the high influence and causal group region. Therefore, policymakers must pay more attention to the critical factors (V3) to cope with the looming energy crisis by developing sustainable wind energy. On the contrary, V4 is the most affected factor placed in the effect group.

The cause-and-effect relationship among the influencing factors is represented in Fig. 6. For 16 factors, the possible maximum relationship number is 16 × 16. Illustrating such a large number of relationships in a single illustration makes it complicated to visualize. Therefore, the threshold value, $\phi = 0.155$, is set in this study.

5. Discussion

According to the prominence ranking shown in Table 5, "Fossil fuel supply disruption (F5)" is the most significant factor in developing sustainable wind energy to support the national grid among all the

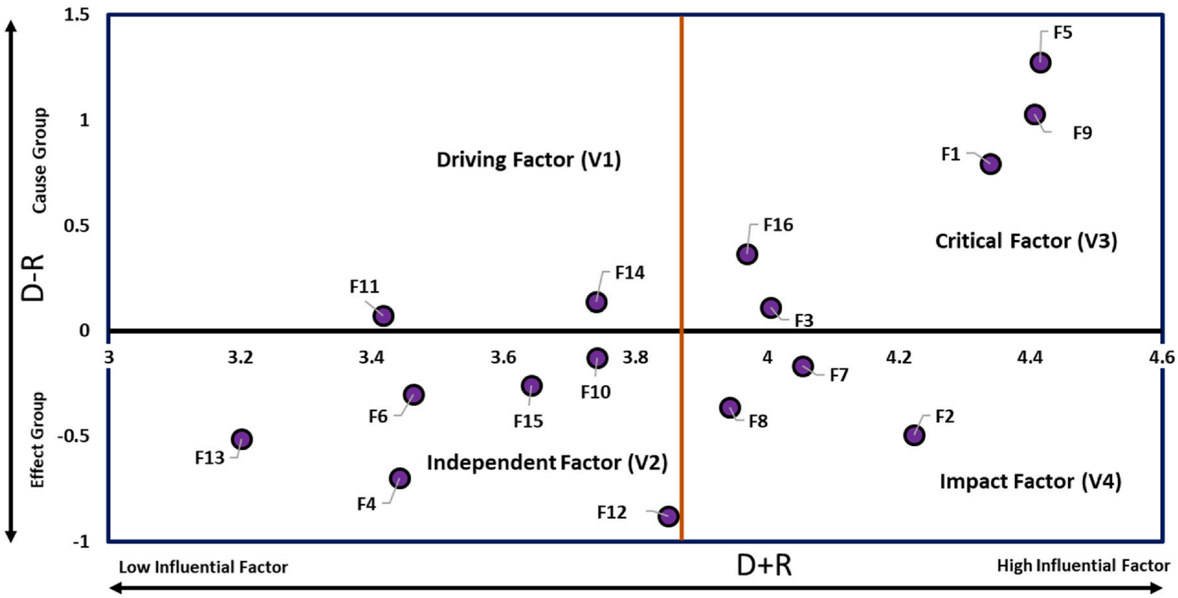

Fig. 5. Representation of the cause-and-effect group of the contributing factors.

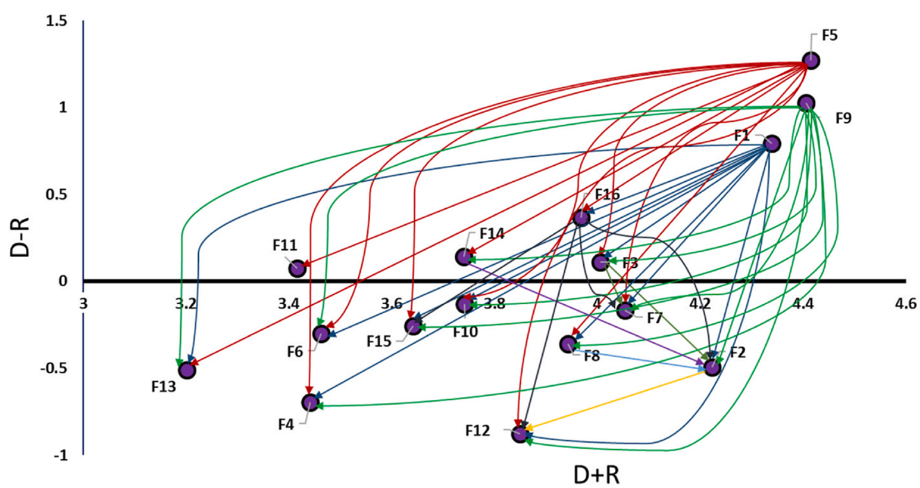

Fig. 6. Co-relationship among the influencing factors.

factors. Global fossil fuel supply disruption is induced by geopolitical polarization, creating uncertainty in the energy sector, while most emerging economies solely rely on fossil fuels in their energy sector [86]. However, emerging economies are eager to avoid the uncertainties of the energy sector caused by evident disruptions of fossil fuels to avoid any impediment to economic expansion [87]. In such uncertain scenarios, sustainable wind energy adoption is an alternative solution due to environmental benefits, carbon neutrality, long-term solutions, financial benefits, and more straightforward energy conservation implementation [88]. Therefore, it is evident that emerging economies must prioritize wind energy adoption, reducing their dependency on fossil fuels to increase resiliency in the energy sector [37].

However, the one main challenge for sustainable wind energy adoption is the stable financial investment to mobilize the resources as the installation cost of sustainable wind energy is higher, resulting in "Stable financial investment and resource mobilization (F9)" as the second significant factor. Emerging economies must subsidize the wind energy sector, which can be accomplished by generating funds globally with international support and collaboration toward decarbonization [89]. Another solution to the problem is to construct several small wind energy plants employing private sector funding [90]. Thus, the small wind plants can support the national grid by keeping carbon neutrality for a particular region. However, funding is not the only single factor in building small wind energy plants, and the plants are needed to construct suitable geographic regions where sufficient wind speed is generated to harness wind energy [91].

Again, "Geographical region (F1)" is the third most significant factor in harnessing wind energy. This is because Bangladesh has many flat lowlands and large coastal offshore and onshore areas, including a 724 km coastal belt and a 200 km hilly coastline, which can produce large amounts of wind energy. Moreover, the monsoon wind originating from the Indian Ocean from March to October flows through the V-shaped coastal line with an average wind speed of 8.5 m/s, generating hundreds of MW of energy [12]. The government of Bangladesh has taken some wind energy projects on mainly the coastal area of Cox's Bazar, with few on flat sites such as Feni, Sirajgonj, Chandpur, and Bagerhat.

However, the regulating authorities are the principal sustainable wind energy adoption stockholders as they set the main strategies behind land use planning and adoption regulations [92]. For example, regulating authorities attract new investors to support energy schemes for installing new wind firms. Moreover, regulating authorities establish emissions regulations, electricity prices, carbon taxes, energy incentives, subsidize wind farms, energy-related legislation, and so on to promote wind energy adoption for carbon neutrality and sustainability [93]. In this process, regulating authorities must overcome obstacles like wind energy diffusion, regulatory and policy risks, economic conditions, political instability, etc. Therefore, "Continuous support and involvement from regulating authorities (F2)" is the 4th significant factor that plays a reliable role in supporting schemes, solving electrical grid issues, and other critical obstacles.

The growing energy demand surge in the national grid is the prime concern for the regulating authorities, the most challenging factor globally due to the industrial revolution, population explosion, economic developments, rapid urbanization, and digital transformation [1]. Therefore, sustainable urban energy technologies with highly efficient sources are required to cope with looming energy surges and negative externalities like GHG, CO_2, and pollutant emissions [94,95]. However, energy generation in urban areas is paramount to generating revenue. Wind energy can be more accessible to meet energy demand, and future running costs can be minimized due to the spontaneous and inexpensive energy source supply [96]. Therefore, "Tackling urbanization-driven energy demand surge (F7)" is the 5th significant factor that benefits urban energy supply in the long run to surpass the initial barriers from an economic and environmental perspective for supporting the national grid.

The commercialization of renewable energy can be another effective way to support the national grid to tackle the energy demand surge, as it will accelerate the growth of wind energy with the help of the private sector [121]. Emerging countries face logistical, financial, and political barriers to sustainable wind energy adoption, where the private sector can develop prominent solutions to looming energy crises [27]. In such circumstances, public-private partnerships can help promote wind energy with advanced technologies, facility growth, robust project implementation, and collaborative research and development [97]. Therefore, "Promoting the commercialization of renewable energy (F3)" is the 6th significant factor as it initiates the rapid growth of sustainable wind energy adoption.

Moreover, the government must come forward with its support to initiate such policies first to cope with the looming energy crisis in the national grid with a carbon-neutral vision. For example, government initiatives and fiscal policies can take immediate steps to prioritize sustainable wind energy adoption in achieving notable success in solving energy crisis issues. The immediate steps can be to set up a definite percentage target of nearly 20 % for using wind energy to increase the share of renewable energy in the national energy matrix [98]. Another step can be tax exemption on using wind energy and imposed taxes, such as carbon tax, particularly in industries that promote clean energy and decarbonization [99]. By creating a "one-stop-shop" office to draw in new investors and speed up the growth of wind energy, the government may collaborate with the regulating bodies to make the licensing of wind energy projects easier [100]. Therefore, the government must invest time, effort, land, fiscal policies, logistical legislation, roadmap, plans, and vision to eradicate the national grid's energy crisis [101]. Thus, Government initiatives can promulgate sustainable wind energy adoption, resulting in "Auspicious governmental initiatives and fiscal policies (F16)" as the 7th significant factor.

Moreover, government and regulating bodies can take necessary tariff policies in the electricity act to integrate policies such as providing credit with the feed-in tariff (FIT) and net metering systems into the energy infrastructure. Although FIT and net metering systems provide predictability, transparency, and energy security, implementing such systems is still fragmented [102]. However, some emerging economic nations espouse new electricity guidelines to implement net metering and FIT systems for on-grid systems [103]. The main challenge for FIT and net metering is the economic effectiveness of the billing scheme with the current tariff policy and the incompatibility of the current infrastructure [104]. Therefore, "Integration of feed-in tariff (FIT) and net metering system into the energy infrastructure (F8)" can be justified as the 8th significant factor if multiple billing schemes can be integrated into the current billing scheme provided that the sufficient infrastructure is prepared to implement FIT and net metering.

According to Fig. 5 and Table 5, "Fossil fuel supply disruption (F5)" is the most influencing and critical factor among all the causal factors. Mainly, the energy sector of emerging economies is heavily dependent on fossil fuels because of their low production cost [105]. When the fossil fuel supply is disrupted, emerging economies look for alternative energy sources to support the growing energy demand in the national grid with cheap costs [106]. Wind energy is renewable, clean, plentiful, available, and requires less land than fossil fuel-based energy production [49]. Therefore, fossil fuel disruption is one of the most influential factors in coping with the looming energy crisis, as fossil fuel alternatives will require stable financial investment, resource mobilization, government support, etc.

"Stable financial investment and resource mobilization (F9)" is the 2nd most influential causal and critical factor. Although the advantages of wind energy over fossil fuel-based energy production, the initial cost of sustainable wind energy plant development is higher, and resources are needed to be mobilized [107]. For resource mobilization, local markets must be formed with positive externalities development. If stable financial investment and resource mobilization can be ensured, they will drive sustainable wind energy along with economic, environmental, and social factors [108].

"Geographical region (F1)" is the 3rd most influential causal and critical factor. Although wind is free, clean, and available to produce energy, the amount of generated power proportionally depends on the wind speed of the wind firm's geographic location. Therefore, the spontaneously generated energy can improve energy supply security, tackle urbanization-driven energy demand surge, land utilization, and compatibility with agricultural activities, and reduce negative environmental footprint [109]. Finally, "Auspicious governmental initiatives and fiscal policies (F16)", "Minimal and economical maintenance (F14)", "Promoting the commercialization of renewable energy (F3)" and "Maximizing cost efficiency potential (F11)" are the following four causal factor among the causal ranking respectively. The government is the main stakeholder in taking the initiative and making favorable fiscal for sustainable wind energy adoption. All the challenges can be overcome if governments push the regulating bodies, proclaim wind energy for society's advantage, create affordable means to ensure energy supply security, reconfigure energy infrastructure with advanced technologies, etc. [110].

Moreover, wind energy requires minimal and more economical maintenance than fossil fuel-based production, resulting in the widespread adoption of wind energy to support the national grid [111]. Wind energy can spread quickly in emerging economies if commercialization can be promoted when the government faces challenges such as less financial support, inadequate infrastructure, energy security issues, capacity mix integration, etc. [112]. Finally, wind energy has better cost-efficiency potential as wind is free, natural, and cleaner than fossil fuel and leverages lower costs. Therefore, cost efficiency potential drives the effect group factors for sustainable wind energy adoption with reduced adverse environmental pollution.

The effect factors are determined in this study (F10 > F7 > F15 > F6 > F8 > F2 > F13 > F4 > F12) poses direct influence from the causal factors. "Land utilization and compatibility with agricultural activities (F10)", "Tackling urbanization-driven energy demand surge (F7)", and "Potential capacity mix integration (F15)" have ranked less influenced in the causal ranking but play a vital role as they are near the cause group. However, they are influenced by the causal group factors. For instance, "Land utilization and compatibility with agricultural activities (F10)" and "Integration of feed-in tariff (FIT) and net metering system into the energy infrastructure (F8)" are influenced by the "Geographical region (F1)" and "Auspicious governmental initiatives and fiscal policies (F16)" factor. Agricultural activities are compatible with wind firms, resulting in proper land utilization, and farmers can consider installing small wind firms to supply electricity with net metering and FIT policy [113]. For this purpose, the government can provide technical and financial support to the farmers, benefiting both the farmers and electricity consumers.

Moreover, "Stable financial investment and resource mobilization (F9)" often impacts the factors such as "Tackling urbanization-driven energy demand surge (F7)", "Potential capacity mix integration (F15)", "Continuous support and involvement from regulating authorities (F2)". The stable financial investment will support the regulating authorities financially to integrate the capacity mix strategy to tackle the urbanization-driven energy demand surge by constructing wind, solar, and hydropower plants together [114]. Moreover, "Reduced negative environmental footprint (F9)" is influenced by "Promoting the commercialization of renewable energy (F3)" and "Fossil fuel supply disruption (F5)". When the fossil fuel supply is disrupted and renewable energy is promoted for commercialization, the wind energy sector can grow more quickly than conventional fossil fuel-based energy production [115]. As a result, the negative carbon footprint will be reduced when the wind energy sector increases.

"Auspicious governmental initiatives and fiscal policies (F16)" and "Stable financial investment and resource mobilization (F9)" factors cause influence over "Continuous support and involvement from regulating authorities (F2)". Mainly, the government supports the regulating bodies with financial support and formulates fiscal policy consulting with the regulating bodies to develop sustainable wind energy [116]. Finally, "Affordable means to ensure energy supply security (F13)", "Social acceptability and adaptability (F4)", and "Improved energy efficiency (F12)" are ranked last as several causal factors, and some effect factors influence these factors.

Fig. 6 depicts that "Fossil fuel supply disruption (F5)" has the most significant causal relationship with other factors, and the causal factors "Stable financial investment and resource mobilization (F9)" and "Geographical region (F1)" are also strongly correlated to other factors respectively. Therefore, policymakers, regulating committees, and decision-makers should emphasize the three factors to facilitate sustainable wind energy adoption to support the national grid.

The findings acquired from this study are significantly different from the other relevant studies [117]. has applied the best-worst method for sustainability assessment of existing onshore wind plants and revealed that the environmental dimension is the most crucial dimension and distance to protected areas is the most important factor in sustainability performance [118]. has applied DEMATEL to assess the offshore wind energy barriers for low carbon energy transition. The study finds that governance is the key influential dimension and that "lack of awareness" is the most influential causal barrier to offshore wind energy development [119]. have applied Delphi, Analytical Hierarchical Process (AHP), and Grey-TOPSIS to rank the barriers, and the result shows that "limited government subsidy" is the most impactful among all barriers and "Availability of adequate funds" is the finest solution for overcoming these barriers in the emerging economics context [57]. have applied the fuzzy analytic hierarchy process to prioritize barriers to offshore wind energy and find that technical barriers are the most crucial, including grid-connection challenges, inadequate testing and commissioning, and lack of energy storage [120]. have conducted a systematic literature review to find out the current trend and criteria for offshore wind energy to support decision-makers. The study revealed that economic feasibility analysis and facilitating access to information for researchers and investors could help offshore wind energy development.

In contrast to the abovementioned studies, our study found that fossil fuel supply disruption, stable financial investment and resource mobilization, and geographical region are the most significant factors in developing sustainable wind energy to support the national grid for carbon neutrality and sustainability in the emerging economy context. However, no previous study has focused on the cause-and-effect relationship prioritizing sustainable wind energy adoption factors, particularly to support the national grid with decarbonization in an emerging economy context. Thus, the framework utilized and outcomes obtained from this study are quite unique and distinguishable from other relevant studies. The strengths and weaknesses of this study are provided in Table 7.

Table 7
Strengths and Weaknesses of this research.

Strengths	Weaknesses
The study combines inter-valued type 2 intuitionistic fuzzy (IVT2IF) theory with the decision-making trial and evaluation laboratory (DEMATEL) method. The innovative methodology allows for a comprehensive analysis of complex factors influencing wind energy adoption with better uncertainty representation.	Due to its unfamiliarity and complexity, this integrated approach involving IVT2IF is often challenging for root-level decision-makers.
Focusing on an emerging economy like Bangladesh adds practical relevance, as these countries often face unique challenges in adopting sustainable energy solutions. The study's findings can potentially provide valuable insights to those countries' decision-makers and policymakers.	While the study focuses on emerging economies, the specific findings may not be 100% applicable to countries with different economic standings.
The initial identification of factors influencing wind energy adoption through a review of existing literature followed by expert validation ensures a comprehensive consideration of relevant factors.	The involvement of expert validation and the subjective nature of some factors may introduce bias into the analysis, potentially impacting the objectivity of the obtained results.

5.1. Theoretical implications

The study contributes significantly to the existing literature with valuable theoretical insights. Firstly, this research yields a significant impact by embracing a holistic view that recognizes the comprehensive analysis of sustainable development, energy crisis, wind energy, emerging economy, and MCDM methodology. First, by focusing on the emerging economy context, this research underscores the possibility of developing nations bypassing conventional energy sources and adopting sustainable alternatives, emphasizing investing in renewable energy to hasten the shift towards a low-carbon future. Second, significant drivers facilitating the growth of sustainable wind energy have been identified and explored using a novel inter-valued type 2 intuitionistic fuzzy DEMATEL MCDM approach in this research. This study's framework can be replicated to investigate the factors contributing to sustainability and resilience in other relevant sectors to guide decision-making processes for adopting and promoting renewable energy sources. Thus, the framework developed in this study can guide decision-makers and researchers to conduct more profound studies and comprehend the factors driving wind energy deployment in diverse economic contexts. This research bridges the existing gaps in the literature and provides a pathway and baseline for future practitioners to explore this area further.

5.2. Practical implications

Policymakers and decision-makers can emphasize the deployment of wind energy as a feasible option in the context of the impending energy crisis driven by disruptions in the supply of fossil fuels. A pertinent implication is to devise policies that facilitate energy diversification. By diversifying the energy mix and decreasing reliance on fossil fuels, leaders and policymakers can bolster the energy system's resilience in supply disruptions. It can be accomplished by establishing targets for adopting sustainable energy, enacting regulations that curtail the use of fossil fuels, and promoting the uptake of alternative energy sources through incentives.

To optimize the efficiency of wind farms, policymakers and developers must make informed decisions about their placement. Wind farms in regions with favorable and consistent winds are more productive and less susceptible to weather-related disruptions. Moreover, wind farms close to transmission lines can facilitate the delivery of electricity to consumers. By strategically locating wind farms, we can harness the full potential of this sustainable and clean energy source. The sufficient coastal areas of Bangladesh support the broad implication of wind energy as a sustainable energy source. With its coastal geographic location on the Bay of Bengal, Bangladesh is a promising location for producing wind energy, thanks to the high wind speeds in the area. Policymakers should take advantage of this opportunity by devising an effective strategy for accelerating the country's implementation of sustainable power generation. Emerging economic countries need to devise their energy policy to facilitate sustainable wind energy adoption. Effective energy policy requires long-term visions to balance economic, environmental, and social considerations with a sustainability and resilience perspective. For this purpose, policymakers must promote wind energy adoption by offering economic incentives to encourage related investments, developing wind energy infrastructures, encouraging research and innovation on wind energy technologies, and formulating proper regulations and standards for wind turbines and other necessary resources.

Moreover, one possible implication for decision-makers is to devise financial incentives and regulatory frameworks that encourage investment in wind energy infrastructure. It could involve tax breaks, subsidies, and expedited permit processes for wind energy ventures. By offering these incentives and stable financial investment, decision-makers and policymakers can stimulate private sector investment and facilitate the growth of wind energy initiatives, resulting in an overall increase in the availability of renewable energy. Allocating resources toward the research and development of wind energy technologies should be a priority. These resources may encompass investments in research and development for improving the effectiveness of wind turbines, exploring novel designs, and advancing the energy storage capabilities of wind energy systems. By prioritizing research and development, policymakers and decision-makers can guarantee the long-term viability and sustainability of wind energy as a source of energy.

5.3. Implications for sustainability

With the looming concerns of energy security and environmental degradation, wind energy has emerged as a promising renewable and sustainable power source. Wind energy adoption includes several implications over the triple-bottom-line of sustainability (economic, environmental, social). Nevertheless, to make a real impact, countries endowed with significant wind energy potential must harness it substantially to satisfy their energy demands.

Adopting wind energy can contribute to SDG 8 (decent work and economic growth) by creating jobs, reducing energy costs, and improving energy security, which in turn stimulates consumer spending and investment and reduces reliance on imported fossil fuels an thus can increase energy security. Moreover, the combination of modern technology, a dependable infrastructure, and low cost make wind power generation an attractive choice among other renewable energy sources, with the most competitive projects priced as low as USD 0.030/kWh [51], making a crucial contributor to SDG 7 (affordable and clean energy). Thereby, incorporating wind energy can strengthen energy security, promote sustainable industrialization, develop resilient infrastructure, and encourage collaboration for new technology development, a vital aspect in achieving SDG 9 (Industry, Innovation, and Infrastructure), by decreasing the reliance on imported fossil fuels as fossil fuel supply disruption is a pressing concern.

With wind energy, nations can take a significant step towards a sustainable future by generating electricity in an eco-friendly manner, thereby minimizing their carbon footprint, NO_X, SO_X, thereby reducing the negative impact of climate change (global warming, rising sea level, etc.) that directly aligns with achieving SDG 13 (Climate action). Moreover, implementing wind energy can improve public health by lowering air pollution and greenhouse gas emissions, which are known to have detrimental health effects, thereby supporting the realization of SDG 3 (good health and well-being).

6. Conclusion

As economic development surges and the global energy landscape evolves, the exploration of electricity consumption and the future of energy in emerging economies like Bangladesh assumes profound importance. During the 27th Conference of the Parties (COP27), Bangladesh, a prominent emerging country in South Asia, highlighted its objective of increasing renewable energy's share in its electricity grid to 40 % by 2041. This objective is especially important at a time when the world is experiencing energy crises and rising inflation, which are both made worse by the ongoing disruptions brought on by the recent COVID-19 pandemic and the Russia-Ukraine war. Sustained expansion in the deployment of wind energy can play a vital role in ensuring both national energy security and the preservation of the global environment.

Utilizing the IVT2IF-DEMATEL-based framework, this study identified and explored the significant factors that exert influence on the adoption and expansion of wind energy. The findings suggest "Fossil fuel supply disruption," "Stable financial investment and resource mobilization," and "Geographical region" to be the three most crucial factors that significantly drive the adoption of wind energy with prominence values 4.415, 4.406, and 4.339, respectively. Specifically, within the cause group, factors such as "Fossil fuel supply disruption," "Geographical region," "Stable financial investment and resource mobilization," and "Auspicious governmental initiatives and fiscal policies" emerge as influential drivers with causal value (D-R) of 1.274, 1.029, and 0.794 respectively that impact the factors in the effect group. "Land utilization and compatibility with agricultural activities" is the most significant factor in the effect group with a causal weight of −0.129, followed by "Tackling urbanization-driven energy demand surge" and "Potential capacity mix integration" with causal weights of −0.166 and −0.256, respectively.

Some factors in the effect group, such as "Continuous support and involvement from regulating authorities" and "Promoting the commercialization of renewable energy," demonstrate a lower likelihood of being influenced by the cause group. Conversely, factors in the effect group, like "Continuous support and involvement from regulating authorities" and "Promoting the commercialization of renewable energy" are less likely to be influenced by the cause group. In contrast, factors such as "Social acceptability and adaptability" and "Affordable means to ensure energy supply security" are highly susceptible to the cause group's influence.

Like others, this study also has some limitations that can be overcome in future research attempts. While IVT2IF DEMATEL is a highly effective decision-making tool, its complexity escalates with more variables. This study focused on 16 variables, necessitating each expert to respond to large ($16 \times 15 = 240$) semi-structured questions to construct the direct-relation matrix, which presents difficulties for human decision-makers. Researchers can leverage artificial intelligence and machine learning to bolster decision-making consistency, enhancing study robustness in the future. This research is mostly applicable to emerging economies like Bangladesh (or other countries with similar economic standing). If this study is to be applied to a country with a different economic standing in the future, an appropriate revision should be carried out to comply with that changed economic perspective. Again, solely the 16 most vital factors from an emerging economy perspective were considered in this study. Additional research in the future might bring more significant and novel factors to light. Moreover, future researchers should make sure that future studies in this context not only involve an in-depth analysis of existing literature but also places a strong emphasis on considering the anticipated forthcoming trends. To stay ahead of the curve and gain a comprehensive understanding of the forces shaping the future in this area, future studies should involve a larger number of experts who are actively engaged in futuristic renewable energy technology-related research. By tapping into the collective wisdom of these experts, future studies will be better equipped to evaluate, detect, and identify new factors that could play a pivotal role in propelling wind energy adoption in the future.

Credit authorship statement

All of the following authors participated in this study.Binoy Debnath - Conceptualization, Methodology, Software, Formal analysis, Visualization, Investigation, Data curation, Writing – original draft, Md Shihab Shakur - Methodology, Software, Formal analysis, Investigation, Data curation, Writing – original draft., Md Tanvir Siraj - Methodology, Software, Formal analysis, Investigation, Writing – original draft, A. B. M. Mainul Bari, Ph.D. – Corresponding Author, Supervision, Conceptualization, Resources, Writing - reviewing & editing, Abu Reza Md. Towfiqul Islam, Ph.D. - Writing - reviewing & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data used in this research are provided either in the manuscript or in the supplementarymaterialsfile

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Appendix A. Supplementary data

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