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Review

Strategic roadmap for offshore wind energy development in Bangladesh: a review

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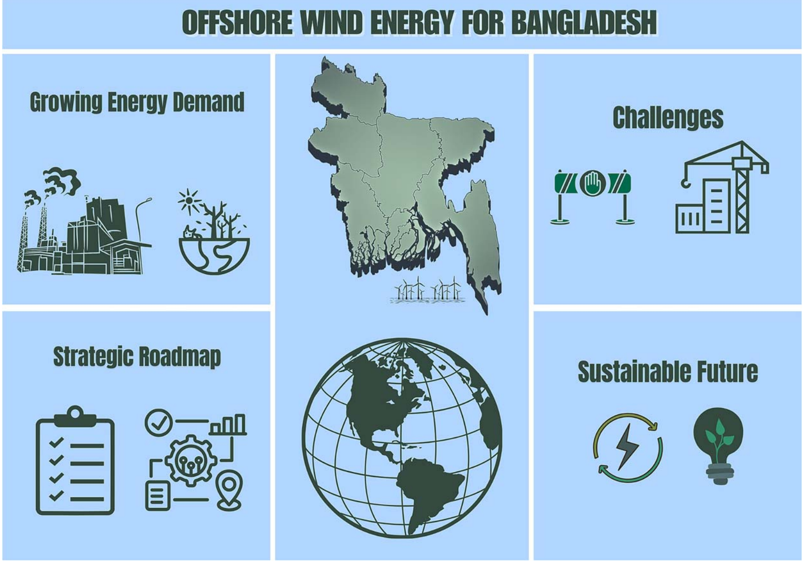
Abstract

Bangladesh is facing a growing demand for sustainable and reliable energy sources due to challenges posed by rapid industrialization and a high dependency on imported fossil fuels. Climate change is another major issue. Offshore wind energy presents a promising opportunity to diversify Bangladesh's energy mix and provide a cleaner source of energy. This review explores the potential of offshore wind energy, wind resource availability at various sites, technological adaptations, and offshore policy frameworks for Bangladesh. The study identifies optimal sites for offshore wind development in Bangladesh, including Cox's Bazar, Sandwip, and the Bay of Bengal. It also identifies key challenges, including the absence of a dedicated offshore wind policy, cyclone resilience, and the effects of high humidity on offshore wind turbines. The paper draws lessons from pioneer countries such as China and the UK to propose a phased roadmap for Bangladesh. Some strategic recommendations are highlighted, such as establishing a national offshore wind authority, adopting cyclone-resistant turbine designs, and implementing financial incentives to attract investment. By addressing technical, economic, and regulatory barriers, Bangladesh can harness enough offshore wind energy to achieve its renewable energy targets by 2041.

Graphical Abstract



Lay summary

Bangladesh explores offshore wind power utilization to tackle increasing electricity demand while trying to minimize the use of fossil fuels. This study reviews research and global experiences to assess opportunities in offshore areas such as Cox's Bazar, Sandwip, and the Bay of Bengal. We find strong potential for offshore wind, but also challenges, e.g. cyclone risks, policy gaps, and high investment costs. We outlined a roadmap for cyclone-resilient turbine designs, dedicated policies, and investment incentives. Offshore wind could help Bangladesh to reach its 40% renewable energy target by 2041 and support sustainable energy development.

Keywords: Bangladesh; offshore wind energy; strategic road map; renewable energy; energy policy

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Introduction

Bangladesh's growing population and rapid industrialization have significantly increased the energy demand within the country. As a result, it is placing considerable strain on Bangladesh's limited natural resources [1]. The growing energy demand has led to frequent power outages and increased electricity costs [2]. Inadequate transmission infrastructure is another big issue for the nation's energy sector [3]. Moreover, the country's heavy reliance on imported fossil fuels and its negative impact on the country's climate change further highlight the urgency of a transition toward sustainable energy sources. The import of electricity, which reached 16 715 million kWh, has raised concerns because it has increased by 60.3% compared to the previous fiscal year [4]. In response to these challenges, the Government of Bangladesh has set ambitious energy targets. The goal is to include total power generation capacity of 40 000 MW by 2030 and 60 000 MW by 2041, and 40% of this capacity is expected to come from renewable sources by 2041 [4]. However, as shown in Fig. 1, the progress has been going slowly in recent years, with hydroelectric power remaining static compared to the previous year and wind energy contributing only 60 MW to the national grid, despite the government's commitments.

Currently, the most widely adopted renewable energy source globally is wind energy, although it is still underutilized in Bangladesh [5]. Offshore wind energy mostly remains untapped in the country. Bangladesh has a 574-km-long coastline with numerous islands. To enhance energy security and contribute to carbon neutrality, the Bay of Bengal presents an opportunity to harness its vast resources and convert them into useful energy [6]. Bangladesh is well positioned to capitalize on the strong south-westerly winds during the summer and the north-easterly winds during the winter months [7]. But the lack of technical expertise, insufficient research, and financial backing are some of the key reasons for the failure to harness wind energy from offshore areas. As a result, the development of offshore wind energy in Bangladesh is still in its early stages and is stalled with several challenges [8].

To fully unlock the potential of offshore wind at the Bay of Bengal and other coastal areas, the government of Bangladesh needs to take some initiatives. Establishing a clear policy framework with financial incentives, long-term power purchase agreements, and regulatory guidelines to attract investment, along with the development of necessary infrastructure such as grid systems and offshore transportation methods to support large-scale projects is crucial in this regard. A good amount of investment in capacity-building initiatives, such as workforce training, R&D on wind resource assessments, and feasibility studies, will also be necessary to identify optimal locations for offshore wind farms. Without strategic actions, Bangladesh might fall behind in the global wind energy market and fail to tackle national energy-related challenges.

Most of the studies conducted in wind energy previously for Bangladesh are on onshore wind energy, and there are few studies that discusses about offshore wind potential in Bangladesh. Table 1 highlights some of the research examining the potential of offshore wind energy in Bangladesh, providing key findings as well as challenges associated with offshore wind energy, but there remain several important research gaps. First, the existing literature does not provide any systematic understanding of policy, technological, and socio-economic considerations, a gap addressed in this review via a phased approach. Second, existing Bangladesh offshore wind feasibility studies do not adequately account for specific risks to the region, such as cyclones, humidity, and seabed issues. This study addresses these specifics through the consideration of cyclone proofing and changes to materials. Third, Bangladesh's energy policies acknowledge offshore wind development, but there are no investment incentives for offshore wind alone, nor protections for marine biodiversity. This paper fills this gap by reviewing international equivalence (e.g. the UK's 'Contracts for Difference' scheme) and providing policy options tailored for Bangladesh. Finally, the socio-economic implications (e.g. fisheries and coastal communities) and the details of techno-economic assessments (e.g. Levelized Cost of Energy) were not addressed in previous studies. Here, these gaps are addressed by proposing Integrated Coastal Zone Management (ICZM) strategies and greater cost modeling. Together, these gaps have been systematically addressed to expand theoretical discussions into practical policy-oriented recommendations for stakeholders.

To respond to the research and knowledge gaps above, this article aims to review the offshore wind energy prospects in Bangladesh. The focus is on the Bay of Bengal and coastal regions such as Cox's Bazar and Sandwip. We will identify resource availability, technological needs, policy gaps, and environmental/social implications. The time frame covered publications between 2000

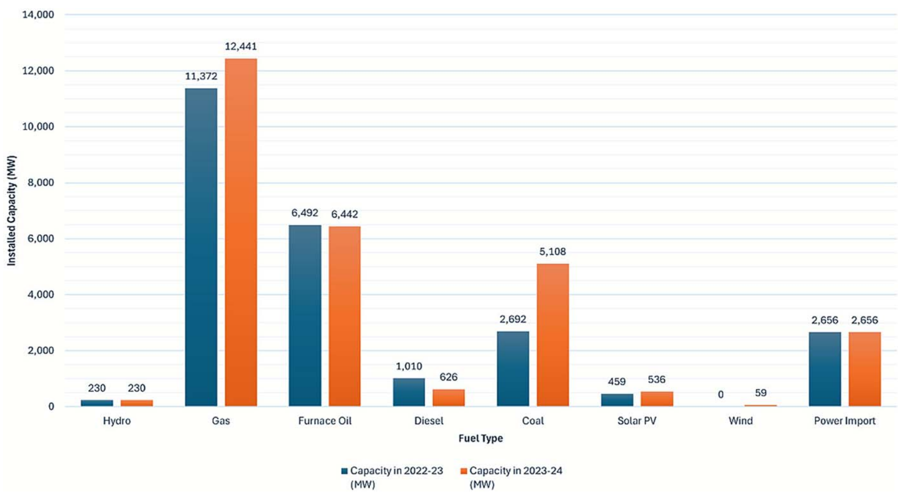

Figure 1. Total energy installed capacity by fuel type 2022–2023 and 2023–2024 [4].

Table 1. Key findings and gaps in some research related to wind energy in Bangladesh.

Research title	Key findings	Research gap
Wind energy analysis in the coastal region of Bangladesh [9]	• Identified Char Fasson and Monpura as high-potential coastal areas with wind speed 7.3 m/s at 100 m height • Suitable for a low-wind-speed wind farm	• Economic feasibility: ROI (return on investment) and cost–benefit calculations are not discussed • Offshore potentiality: discussed coastal sites, ignored deeper offshore locations • Policy gaps: no recommendation for government or industry adoption
Present energy scenario and future energy mix of Bangladesh [10]	• Proposed energy mix possibilities until 2041: 25% coal, 25% gas, 35% renewables • Highlighted land scarcity and policy barriers for the deployment of renewable energy	• Grid resilience: no discussion found on grid modernization and its challenges for various renewables • Emerging technologies: the hybrid solar–wind system was not explored
A wind energy potential, progress, and challenges in Bangladesh: a review [11]	• Discussed coastal and offshore locations such as Char Fashion, Cox's Bazar, having wind speeds >7 m/s at 100 m height • Highlighted the already running 60-MW on-grid onshore wind farm at Cox's Bazar as a milestone for Bangladesh • Estimated CO_2 reduction potential • Reviewed the gaps between global wind energy trends and Bangladesh wind energy trends	• Data scarcity: the study highly relied on inconsistent Bangladesh meteorological data • Economic viability: no detailed LCOE or ROI calculation and cost–benefit analysis • Grid integration: no study on storage solutions • Offshore potential: limited exploration • Social and environmental acceptance: no study on local community resistance, bird/bat collision risks for the Bangladesh ecosystem
Offshore wind energy estimation in the Bay of Bengal with satellite wind measurement [12]	• Developed the first offshore wind atlas for the Bay of Bengal using satellite data (ASAR) • Studied a test case of a 400-MW wind farm having 1693 GWh AEP	• Validation gap: no ground-truth data to validate satellite models • Feasibility: missing LCOE or project financing insights • Social and environmental acceptance: environmental (marine life) and social (fishing community) impacts are unaddressed
Potentiality of wind power generation along the Bangladesh coast [13]	• Found peak wind speed 3–6 m/s from June to August near coastal areas • Highlighted offshore wind potential during the April–August period • Proposed policy incentives: tax exemptions, subsidies, and FDI for wind energy development	• Data limitations: lacks data validation, relies heavily on remote sensing • Economic barriers: no cost analysis for wind projects shown • Seasonal dependency: no solution proposed for low-wind-speed months (October–February) • Social and environmental acceptance: no assessment of the coastline communities (fishing, tourism) or marine life
A critical analysis of wind energy generation potential in different regions of Bangladesh [14]	• Found Sandwip as a potential location for wind energy, having an average wind speed of 4.89 m/s at 50 m height, peaking at 5.18 m/s • A resource assessment was conducted using the Weibull probability function and found that the power density method is best for potentiality analysis • Suggested Enercon E-40 and E-48 as suitable wind turbines for Sandwip • Wind energy density found for Sandwip is 281.10 kWh/m^2 in July, and wind power density peaking at 243.20 W/m^2	• Data validity: reliance on data from NASA without validation from a ground test measurement or long-term location data • Economic analysis: no LCOE or payback period calculations for proposed wind turbines • Grid integration: no study on storage requirements and grid stability • Environmental impact: nothing highlighted on ecological and environmental effects (bird collision, marine life, noise pollution) in Sandwip
Offshore wind energy fundamentals for Bangladesh (NREL and USAID) [15]	• High offshore potential near Cox's Bazar and Matarbari with average wind speed 6–8 m/s at 160 m hub height • Proposed floating OWT for deeper seawater zones and fixed-bottom OWT for shallow-water sites • Emphasized port infrastructures and grid upgrades	• Seabed analysis: lack of high-resolution seabed surveys for precise turbine sitting • Economic viability: no detailed LCOE comparison shown on floating and fixed-bottom OTW for the Bangladesh sea conditions • Environmental aspect: showed minimal assessment on marine ecosystem disruption • Social acceptance: there is no study about the impact on the livelihood of coastal communities

and 2025, with an emphasis on the last decade (2015–2025) to capture recent technological, policy, and environmental developments. Sources were gathered from Scopus-indexed journals along with gray literature from International Renewable Energy Agency (IRENA), Global Wind Energy Council (GWEC), World Bank, National Renewable Energy Laboratory (NREL), and Bangladesh Power Development Board (BPDB).

The analysis is structured into four main themes:

- Wind resource potential: evaluate wind speed, wind power density, and site suitability in Bangladesh.
- Technological adaptations: cyclone-resilient turbines, floating versus fixed foundations, and material durability in humid/marine environments.
- Policy and governance: absence of dedicated offshore wind policy, need for institutional frameworks, and lessons from international experience.
- Environmental and socio-economic: impacts on biodiversity, fisheries, livelihoods, and integration into coastal zone management.

The analysis compared policy maturity, financing models, and technological readiness between global leaders and Bangladesh. The findings of the above themes were consolidated into a strategic roadmap for Bangladesh.

Offshore wind technology

For more than 200 years, onshore wind technology has been used, and in recent years, it has undergone a very successful technical revolution [16]. Offshore wind farms are gradually starting to thrive since offshore wind energy technology has developed significantly [16]. The growing field of offshore wind technology started to flourish in the 2000s, even though the technology had been established for three decades [17]. Onshore and offshore wind technologies differ primarily in their installation environments for foundation, which is considerably more complicated in the sea for both design and construction, and operation [18, 19]. Compared to onshore wind farms, offshore wind farms have greater flexibility in choosing their places of operation. Additionally, offshore wind farms are often situated distant from crowded locations, meaning that communities are less affected by noise and appearance [16].

There are several foundation options for offshore wind turbines, and the choice relies primarily on the terrain, water depth, and turbine size [20]. There are two types of offshore wind turbines (OWTs), depending on the depth of the water: fixed-bottom OWT and floating OWT [21].

Fixed-bottom wind turbines

Fixed-bottom OWTs are generally of three types such as tripod substructure type, monopile substructure type, and jacket substructure type, shown in Fig. 2.

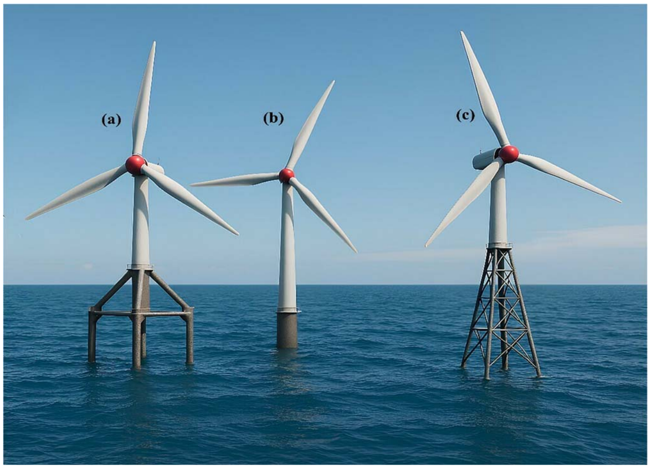

Figure 2. Fixed-bottom offshore wind turbine: (a) tripod substructure, (b) monopile substructure, (c) jacket substructure.

(a) **Monopile substructure**: In shallow water (≤40 m), monopiles are the most commonly used substructure foundation for contemporary offshore wind farms. Usually 4–6 m in diameter and up to 1000 tons in mass, these monopiles are made of steel tubular sections, or pipe piles, which carry the applied vertical and larger lateral loading onto the bottom foundation [19].

(b) **Tripod substructure**: At ≥45 m, tripod substructures are a cost-effective option and ideal for areas with medium-to-dense sands or stiff clays, but adaptable to gentler soils as well. A large-diameter central steel tubular section and the seafloor are joined to three-legged tripod bases to form tripods. To improve the stability and stiffness of the entire offshore wind turbine substructure, these three piles are buried 10–20 m into the seabed [22]

(c) **Jacket substructure**: For deeper water up to 60 m, a jacket or braced frame substructure is generally used [22]. Like tripods, jacket frame structures are made of a lattice frame of small-diameter steel struts that are secured to the seafloor using one of the various foundation solutions. Because the strut components provide less resistance to the dominant ocean waves and current flow than monopile or tripod structures, braced frame structures are especially well suited for harsh maritime weather [19].

Floating wind turbines

The four main types of floating OWTs are spar buoy, semi-submersible, tension leg platform (TLP), and barge, shown in Fig. 3.

(a) **Spar buoy**: One of the most established offshore wind energy technologies is the spar-type floating wind turbine (FOWT) concept, which was initially operated in Statoil's Hywind project in 2009 and then in Scotland's first commercial floating wind farm in 2020. By employing the correlation between buoyancy and gravity, the spar-type floating platform provides stability by placing its center of gravity far below its center of buoyancy. Because of its huge draft and lengthy submerged column, this design requires deep seas (usually >100 m). But it produces superior stability and resistance to currents. The platform is made up of a deep-draft vertical cylinder for buoyancy and a catenary or semi-taut mooring system for station-keeping. It can be ballasted vertically after being dragged horizontally [22, 23].

(b) **Semi-submersible**: The semi-submersible type is widely used for offshore wind turbines, particularly suitable for deeper waters (50–300 m). Semi-submersible platform foundations are now frequently used for floating wind turbines since they can withstand a greater range of water depths and are better suited for turbines >10 MW. Additionally, when supporting larger-capacity units, semi-submersible foundations provide considerable cost advantages [20]. Around the turbine, a semi-submersible floating platform is made up of dispersed buoyant floats that enable controlled

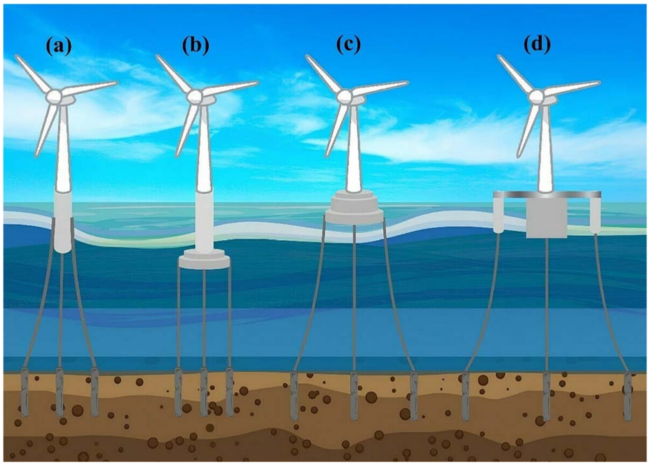

Figure 3. Floating offshore wind turbines: (a) spar buoy, (b) tension leg, (c) barge, (d) semi-submersible.

buoyancy and gravity modifications to preserve stability against outside influences like wind and currents. The platform is quite flexible thanks to this control system, but it is also complicated, especially in challenging marine conditions. Semi-submersibles have comparatively modest drafts compared to spar platforms, which is advantageous because it allows for quayside assembly and wet towing [22, 23].

(c) **Tension leg platform (TLP)**: TLPs are stable and economical in deep waters, and they are extensively used in the oil and gas sector. They are now becoming more and more popular as floating offshore wind turbines (FOWTs). Comparing them to other floating foundations, they show less heave, pitch, and roll motion, which makes them ideal for offshore wind applications. With tensioned tendons attached to permanent piles, the platform is secured to the seabed since its buoyancy is much higher than its gravity. Tendon strain and surplus buoyancy work together to provide stability, which maintains the platform's vertical stability. But because of the high-tension pressures they endure, these tendons carry the risk of being damaged or possibly failing structurally [22, 23].

(d) **Barge:** Barge-type FOWTs are inexpensive and simple to construct since they use platform buoyancy to defy gravity. Usually, a big, shallow-draft barge is equipped with one or more wind turbines. A sizable waterplane area ensures stability, and they enable wet towing and quayside assembly, just as semi-submersibles. The main benefit of barge-type platforms is their straightforward production method. Their applicability for calm waters, like harbors or places with little wave activity, is limited by their extreme sensitivity to seawater variations, roll, and pitch motions [22, 23].

Global offshore wind project trends

A total of 10.8 GW of new offshore wind was put into service globally in 2023, increasing the total offshore wind capacity worldwide to 75.2 GW. The year 2023 was the second-highest year for new offshore wind capacity, with additions of offshore wind being 24% greater than in 2022 [5]. China is one of the world's largest energy consumers [24]. As of 2020, China's offshore wind installed capacity accounted for 1.6% of its overall wind power commitment [25]. However, with the recent growth of offshore wind in Europe, advancements in technology, and the development of the offshore market outside of Europe, China has placed a lot of attention on offshore wind power to make it profitable [25]. China now leads the world in offshore wind development, with 6.3 GW put into service in 2023, accounting for 58% of all additions worldwide and increasing its total offshore wind installations to 38 GW [5, 26].

Elsewhere in the Asia-Pacific region, three markets commissioned new offshore wind capacity last year: Taiwan (China) (692 MW), Japan (62 MW), and South Korea (4 MW) [27]. The total operational offshore wind capacity in the UK seas was a little over 7000 MW in June 2018 [28]. At the end of 2023, it rose to 43% for the UK in the European offshore market and 24% in Germany [5, 29]. Strong growth of offshore wind in the Netherlands helped Europe to score a record year in 2023, with 3.8 GW of new offshore wind capacity commissioned across six markets. This brought Europe's total offshore wind capacity to 34 GW by the end of 2023 [5]. The USA has made infrastructure and is gradually transitioning to a clean energy economy by setting a goal of deploying 30 GW of offshore wind capacity by 2030 and emphasizing deploying 110 GW or more offshore wind energy by 2050 [30].

For large-scale, renewable power generation, offshore wind presents an alluring alternative for developing nations like Bangladesh [31]. Offshore wind development is a complicated process that needs both dedication and strategic vision. In contrast to onshore wind and solar, offshore wind is unlikely to reach its full potential without substantial government support and policies. Establishing a distinct national role for offshore wind, from both an energy and socio-economic standpoint, is essential to a successful strategy. For instance, the UK and Denmark explicitly state strategic reasons why offshore wind is important to their long-term energy plans. It makes it easier for stakeholders to comprehend why the nation is pursuing offshore wind and what the purpose is before investing time, funds, and resources in such big projects [32].

Potential of offshore wind in Bangladesh

Since offshore wind is relatively new for Bangladesh, there is a need for a high-resolution wind resource map, particularly for its high-wind-speed offshore areas [9]. Some available satellite data show that offshore wind speeds are much higher in coastal regions compared to onshore areas [10]. Synthetic aperture radar (SAR)–based datasets indicate substantial offshore wind potential for Bangladesh [11, 12], with consistently high speeds from April to August and relatively strong winds in other months as well. At 10 m height, offshore wind speeds range from 3 to 6 m/s during April–August, with the highest recorded offshore wind speed reaching 7.5 m/s at 120 m height in offshore areas, making offshore wind farms a highly effective option for Bangladesh [8, 13]. A comprehensive study has identified the offshore area near Sandwip as an ideal location for wind power generation at 50 m height**,** with a power density of 88.6 W/m^2 and a capacity factor close to 21%, making it better suited for small-scale or hybrid applications [14]. Feasibility studies and assessments, sponsored by the Asian Development Bank, have identified suitable offshore wind development sites off the coast of Cox's Bazar (Fig. 5), where research shows offshore wind speeds at a 160-m hub height range from 6.3 to 8.0 m/s, with fixed-bottom OWT technology suitable up to 60-m water depth [15].

Recent high-resolution datasets from the Global Wind Atlas 4.0, Global Atlas, and ERA5 reanalysis confirm these findings. It has been indicated that potential areas for offshore wind near

Figure 4. Monthly average (a) wind speed and (b) wind power density of prospective offshore location in Bangladesh [33].

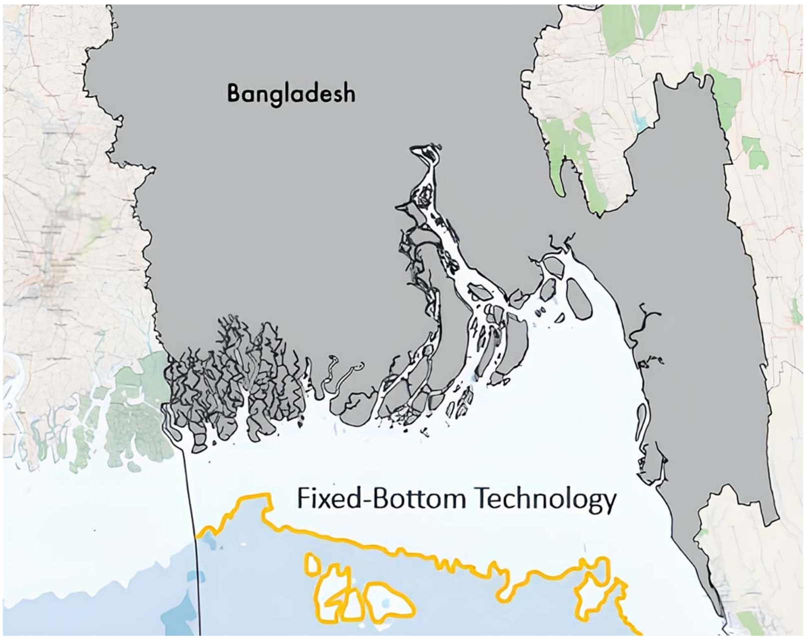

Figure 5. Planned area for fixed-bottom OWT project at 60 m depth at bay of Bengal of Bangladesh [15].

Table 2. Prospective location data for offshore wind in Bangladesh [33, 34].

Location	Wind speed (avg) m/s	Wind density (avg) W/m^2	Capacity factor %
Cox's Bazar (near shore)	5.8	206	32
Sandwip	5.9	210	31
Matarbari	6.0	223	31

Cox's Bazar deep sea area, Matarbari, and Sandwip exhibit wind power densities between 200 and 250 W/m^2 within 100 to 160 m height (refer to Fig. 4(b)) [33]. The potential capacity factors are between 30% and 35% for modern offshore turbines (refer to Table 2) [34].

Seasonal analysis reveals a pronounced pre-monsoon and monsoon peak (April–September), during which average wind speeds are 20% to 40% higher than in the dry season (October–March), consistent with regional climatology (refer to Fig. 4(a)). The peak also indicates that this period is a high point in wind potential and a perfect time for harvesting wind energy. Given these resource levels and seasonal patterns, Bangladesh's offshore wind sector shows strong prospects, with national targets aiming for 6 GW of offshore capacity by 2041 and 15 GW by 2050 [15].

Gaps in Bangladesh's renewable energy framework for offshore wind

The current energy policy of Bangladesh is not conducive to offshore wind energy development. According to the Renewable Energy Policy 2008 and the Power System Master Plan 2023 [35], there are broad objectives for national renewable energy, but missing provisions for offshore wind energy projects. Important gaps remain in implementation guidelines, financial incentives, and regulatory coordination requirements, which are fundamental to attracting private investment [4, 32]. Bangladesh's governance framework for offshore wind energy development is further complicated by its multiple ministries that often fail to coordinate their efforts. This form of governance builds uncertainty into the regulations, delaying project development. In contrast, the governance structures in place in Europe and China create far less project uncertainty. For example, Europe and China employ feed-in tariffs (FITs) and standardized permitting processes, minimizing the risk of regulatory uncertainty, while also fast-tracking project development timelines. The governance of offshore wind energy relates to technical standards and environmental concerns as well. For example, the Grid Code (2018) was designed for interconnected energy resources that primarily produce energy from conventional resources, with no standards for integrating offshore wind energy. The Environment Conservation Rules provided minimal standards for conducting environmental impact assessments to limit harm to existing marine ecosystems [3, 36]. In addition, as a dominantly coastal state, it is problematic that Bangladesh lacks marine spatial planning, increasing the possibility of conflict with commercial fishing industries and shipping lanes. Bangladesh has some shortcomings in the offshore wind sector, but there is also a well-suited opportunity to capitalize on in the Bay of Bengal [5]. To move forward, the country should review its offshore wind policy. The review should set clear targets for offshore wind sector, explore financial opportunities, and create a governance system that reduces fragmentation. The government of Bangladesh should also ensure efficient and effective regulation to support sustainable offshore wind energy development.

Environmental and social implications of large-scale offshore wind deployment in Bangladesh

In order to achieve long-term sustainability, the environmental and social implications associated with large-scale offshore wind energy projects will require proper concern. The offshore projects can provide cleaner energy generation and reduce carbon emission problems, but doing so, they will also have influence on sensitive marine ecosystems and coastal people's livelihoods. The Bay of Bengal hosts diverse species and active fishing communities. Their existence must be protected through careful planning as first priority. Assessing these implications is critical to ensure that offshore wind development complements, rather than disrupts, existing ecological and economic systems. This section explores the key environmental effects, community-level challenges, and mitigation strategies necessary for responsible offshore wind expansion in Bangladesh.

Environmental and socioeconomic considerations

The Bay of Bengal sustains hundreds of fishing communities and is home to various marine habitats. The Bay's productivity highly depends on keeping it healthy, which is essential to Bangladesh's long-term GDP growth. The country's social and economic growth, as well as the regional ecological balance, have benefited greatly from the coastal and marine fisheries, such as shrimp and crab aquaculture [37]. Besides, the Bay of Bengal's marine ecosystem is one of the largest recognized marine ecosystems among 66 large marine ecosystems worldwide [38]. These natural habitats serve as pollution filters, stop shoreline erosion, offer food and shelter, and serve as nurseries for a variety of aquatic animals [39]. Therefore, any offshore wind project must carefully consider how it will affect fisheries, coastal livelihoods, and marine biodiversity [36, 40]. Also, it will require necessary consultations with stakeholders and appropriate environmental impact studies of offshore wind projects for such locations in Bangladesh.

Offshore wind farms need a planning framework that is completely compatible with terrestrial planning systems and demands a substantial quantity of marine space [41]. Given the demand, integrated coastal zone management (ICZM) and marine spatial planning (MSP) are crucial procedures that can be used in Bangladesh's renewable energy industry [42]. The setting up of wind farms must be balanced with regulatory requirements that provide guidelines for safeguarding and conserving maritime biodiversity. To provide baseline information about potential development sites and seabed cabling routes, as well as to aid in decision-making regarding the avoidance of conflicts with other uses of the marine environment, the first step is to make sure that the wind energy resource and the seabed are thoroughly surveyed and mapped [43]. Additionally, species that may be harmed by active wind farms, such as several seabird species, must be carefully considered during the project period. Lastly, another thing to keep in mind is the development of artificial and novel substrates, which might encourage the colonization of invasive species and the introduction of non-native species, which can change the balance of biodiversity in the area [44, 45].

Marine biodiversity and ecosystem

The installation of wind turbine foundations can produce underwater noise, and the subsea cables may disrupt seafloor habitats and benthic communities by causing sediment resuspension [46, 47]. Additionally, the constructed turbine structures and mooring lines often evolve into artificial reefs, attracting mussels and fish for colonization, which increases biomass and habitat complexity [46, 48]. The construction of foundations on various seabed types also impacts biodiversity throughout their life cycle. For example, sandy seabed may see short-term biodiversity gains that last ∼13 years before declining over 25 years, while hard seabeds may support long-term increases in biodiversity [49]. Offshore wind farms can enhance food web productivity by up to 40% due to artificial reef formation and the resulting increase in biomass [50]. On a larger scale, the installation of wind farms may affect water column stratification and pelagic productivity by up to 8%, potentially altering primary production cycles [51].

Impacts on fisheries and coastal communities

Fishing areas near wind turbine locations may face challenges for trawling and other fishing methods due to turbine foundations, especially those with anchoring systems, potentially reducing access to catches [52]. Offshore projects can also cause seabed disturbances, noise, and increased vessel traffic, which may negatively affect commercial fishers [53]. However, projects like Ocean Wind 1 have introduced initiatives to support fishing communities, including fisheries liaison roles, gear-claim procedures, and navigational safety funds, setting a precedent for community compensation [53].

Social acceptance and stakeholder engagement

A study in Taiwan found that local stakeholders' acceptance of offshore wind farms, particularly among fishers and aquaculture operators, is largely driven by the perceived benefits of such projects [54]. However, protected coastal areas require careful examination before initiating any projects. For instance, a case study in Brazil's Ponta do Tubarão reserve revealed that wind projects disrupted ecosystems and livelihoods, negatively affecting fishing access, local culture, and biodiversity [55].

Recommended mitigation strategies for Bangladesh

To ensure sustainable development and mitigate potential risks, it is crucial to implement comprehensive strategies that balance environmental preservation with economic growth. Below are several recommended mitigation strategies for Bangladesh to address the challenges posed by offshore wind energy projects.

1) **Adopt integrated coastal zone management (ICZM) and marine spatial planning (MSP):** High biodiversity areas should be protected through careful planning to minimize ecological impacts.

2) **Life-cycle impact assessment:** An assessment should be done to integrate biodiversity metrics, decommissioning strategies, and projections of species migration [49].
3) **Fisheries support programs:** Taking Ocean Wind 1 as an example, fishermen's liaison committees, compensation protocols, and safe navigation guidelines should be created for the benefit of the fishing community [53].
4) **Environmental monitoring and adaptive management:** Pre- and post-construction surveys need to be implemented to track reef development, noise levels, and ecosystem changes.
5) **Stakeholder co-design approaches:** Engage local fishers in early stages of planning, employ community outreach campaigns, and assess perceptions by following strategies applied in Taiwan [54].

Technological challenges and adaptations

Bangladesh's offshore environment poses unique challenges. Bangladesh is a country that frequently encounters natural disasters, such as tropical cyclones and storm surges, which jeopardize its economic growth and result in significant fatalities each year [56, 57]. The majority of tropical cyclones make landfall in April to May and October to November. A major caution for the coastal zone is the rising frequency of intense tropical storms and their shorter return periods [57]. In this regard, adaptation to such conditions is imperative for any offshore wind project. To forecast uncertain tropical storms, the probability of tropical cyclones can be estimated using various potential wind distributions. In this context, the Poisson distribution is commonly used, and its suitability has been strongly proven [58]. To evaluate the economic impact of hurricane or tropical storm damage, different building damage models can be developed [59]. It aids in measuring wind loads and, consequently, the degree of wind damage to turbine parts [59].

Another issue in Bangladesh's offshore regions is high humidity. Bangladesh's average annual humidity is 79% approximately [60]. It is rising every year, and it may affect the wind turbine's aerodynamic performance. The energy output can be negatively impacted due to high humidity, molds, and rust [61]. Persistent humidity and saline air accelerate blade surface erosion, electrical insulation breakdown, and corrosion in gearboxes and bearings, all of which can reduce turbine efficiency over time [62]. Studies of offshore wind structures in tropical marine climates shows significant performance reduction over time when anti-corrosion measures are inadequate [63, 64]. For Bangladesh, where annual mean relative humidity goes above 75%, innovative turbine designs with more robust foundations, anti-corrosion materials, and real-time monitoring systems will be essential to address the issues related to wind turbine performance [65–68]. Some mitigation measures should include marine-grade anti-corrosion coatings such as ISO 12944 C5-M, sealed nacelles with active dehumidifiers, and regular salt–moisture exposure testing to prevent material fatigue [69–71]. Condition-based monitoring systems with humidity and salt sensors can further improve operational reliability which will detect early signs of corrosion or moisture ingress. Dehumidification systems using adsorption or refrigeration principles have already proven effective in maintaining low internal moisture levels in turbines operating under marine tropical conditions [72, 73]. Another option is to turn off turbines during high-humidity conditions [74]. Frequent blade maintenance and inspection can assist in detecting and resolving possible issues brought on by humidity, such as rust or coating deterioration.

Techno-economic feasibility and cost analysis

Techno-economic feasibility

Offshore wind energy offers significant long-term benefits, including price stability, reduced dependency on energy imports, and economic growth through the development of a local wind energy sector, although its initial investment costs are high [6, 75]. The techno-economic feasibility of offshore wind in Bangladesh is determined by various interdependent factors, such as wind resource availability, capital and operational costs, infrastructure development, grid integration, and financial viability. Studies indicate that the Bay of Bengal possesses considerable offshore wind potential, with wind speeds reaching commercially viable levels. To optimize site selection and maximize energy production while minimizing investment risks, the implementation of high-resolution wind resource mapping through advanced satellite data and numerical modeling is crucial for offshore wind energy in Bangladesh [76–78].

In addition, upgrading grid infrastructure and transmission networks will facilitate efficient power distribution from offshore wind farms [79]. Establishing dedicated ports and manufacturing facilities for wind turbine components can also contribute to cost reduction by improving logistical efficiency [80]. Encouraging domestic production of wind turbine components and enhancing technical expertise within Bangladesh can help mitigate costs [66]. Furthermore, partnerships with international firms can accelerate technology transfer and capacity building. The adoption of floating offshore wind technology can expand opportunities for harnessing wind energy in deeper waters with higher wind speeds [81]. Additionally, advancements in turbine technology and turbine efficiency, energy storage, digital monitoring systems, and potential financial incentives will further enhance the viability and sustainability of offshore wind energy in Bangladesh [66].

Initial investment costs for offshore wind farms are significantly higher than onshore projects due to expenses related to foundations, transmission infrastructure, and maintenance in harsh marine environments [82]. The economic viability of offshore wind energy is determined by several key financial factors, including capital expenditures (CAPEX), operational expenditures (OPEX), and the levelized cost of electricity (LCOE) [83–86]. The establishment of a transparent and stable regulatory framework comprising long-term power purchase agreements, feed-in tariffs, and tax incentives will be essential for attracting both domestic and international investments [87, 88]. Additionally, financial mechanisms such as public–private partnerships (PPPs), green bonds, concessional financing, and international climate funds can play a crucial role in supporting offshore wind development in Bangladesh [89].

Furthermore, the creation of specialized training programs and research centers will contribute to the development of local expertise in offshore wind engineering, maintenance, and policymaking, thereby reducing reliance on foreign specialists. While offshore wind energy has the potential to enhance Bangladesh's energy security and promote sustainable development, a comprehensive feasibility assessment encompassing technical, economic, and regulatory considerations is imperative for its large-scale implementation.

Cost analysis of electricity generation from offshore wind

Understanding the costs of offshore wind energy is crucial for knowing whether it can truly stand as a viable alternative to traditional energy sources. By examining these costs, clear insights can be found on its feasibility, long-term benefits, and the kind of support it needs to compete in the energy market.

A recent study was conducted considering 50 numbers of 2-MW turbines on a 25-km^2 area. It considers the cost of the levelized cost of energy (LCOE) for a 10-year lifespan, insurance premiums, and even the manpower cost. The cost of electricity generation from onshore wind turbines is 6.08 BDT/kWh (0.05 USD/kWh) [90, 91]. While the cost is very low, with natural gas being the cheapest (3.10 BDT/kWh) (0.025 USD/kWh) and solar PV being the most expensive (80.68 BDT/kWh) (0.66USD/kWh), the study shows that most of the cost occurs due to land purchase [90, 91]. For offshore wind energy, detailed cost analysis is still limited. Because of this, the study uses onshore wind energy generation as a reference point, while making adjustments to better reflect offshore conditions. In this approach, the cost of land is excluded, but the cost of transmission is included since transmission is a significant factor offshore. Additionally, 10% of the typical land cost is added to the installation of structures to account for the extra challenges involved in building and maintaining offshore systems. A reference transmission cost was taken from existing research that estimated the breakeven cost of transmission for both HVAC and VSC-HVDC systems. According to that study, the cost of transmitting electricity over a distance of 80 km was calculated to be 15 million USD [92]. Calculating the changes, the cost of electricity per kilowatt-hour would be 1.64 BDT (0.013 USD), making it the cheapest source of energy and a viable clean energy alternative to fossil fuels [91, 93].

Foreign investment aid

Bangladesh is attracting significant international investment to grow its renewable energy sector. The European Investment Bank has approved a €350-million (~406 million USD) loan to support the country's renewable energy projects [91]. This funding will help strengthen Bangladesh's energy infrastructure, particularly through large-scale solar and wind projects, to add ~750 MWp of new renewable capacity. This investment reflects a strong dedication to sustainable development and climate action, aligning with Bangladesh's goals to boost the role of renewable energy in its overall energy supply [94].

Comparative analysis of offshore wind: Bangladesh versus global peers

Bangladesh is still in the early phases of developing offshore wind energy. So, a comparative assessment of offshore wind energy planning, the experiences, and the unique and insightful approaches chosen by Asia-Pacific coastal countries such as China, India, and Vietnam, and outside of Asia (the UK), offers valuable lessons for Bangladesh in understanding what drives success in this field. Research showed (Table 3) that having proactive policies, investing in infrastructure early on, and forming strategic international partnerships are crucial for boosting offshore wind capacity. Bangladesh needs a clear, data-driven strategy. This should include strong regulations, smart grid plans, and incentives for investors. Additionally, Bangladesh should consider diverse financing models, such as PPPs, foreign direct investment (FDI), and climate funds, to attract both local and international investments. Bangladesh can follow UK as an example. They utilized PPPs to develop large-scale offshore wind projects named Hornsea Wind Farm. This farm is known as the world's largest offshore wind farm. It has been established with significant private investment alongside government support [95]. Similarly, foreign direct investment (FDI) played a key role in the establishment of offshore wind projects in countries like China, which has attracted substantial foreign capital for its projects, particularly from European industries [96]. Additionally, Bangladesh can explore climate-related funds, such as the Green Climate Fund (GCF). This fund provides concessional grants for climate-related projects, including renewable energy projects like offshore wind [97]. All of these options can provide the necessary capital to transform technical potential into actionable projects, ensuring long-term sustainability in offshore wind energy development.

- **UK**: The UK is a global leader in offshore wind energy, with an established regulatory framework that has driven industry growth. The UK's Offshore Wind Sector Deal (2019) is a landmark policy document that lays out a strategic vision for offshore wind, including investment in local supply chains, research and development, and job creation [101]. The Contracts for Difference (CfD) scheme guarantees fixed, long-term prices for offshore wind energy, attracting both domestic and international investors. This model has allowed the UK to reduce offshore wind costs significantly, making it a competitive source of energy.
- **China**: China's offshore wind development is centrally driven by government policies, with substantial state-backed investments and a push for local manufacturing capabilities. China's 13th Five-Year Plan for Renewable Energy (2016–2020) included ambitious offshore wind targets, focusing on expanding the industry through centralized tenders and regional pilot projects [100]. The Chinese government also supports the creation of local infrastructure and technology manufacturing, reducing reliance on imports. Moreover, China has made progress in establishing grid integration systems for offshore wind energy, ensuring that power generated offshore can be transmitted efficiently to key demand areas.
- **Vietnam**: Vietnam is in the early stages of developing offshore wind energy but has implemented policies such as FITs to incentivize private investment. The National Power Development Plan for 2021–2030 (PDP VIII) aims to accelerate offshore wind development, with government targets and regulations guiding this process. Unlike Bangladesh, which lacks clear offshore wind targets, Vietnam's FITs offer price guarantees for offshore wind projects, fostering a more predictable investment environment [102]. The government's approach includes provincial-level targets for offshore wind capacity, which could serve as a model for Bangladesh.
- **India**: India, with its vast coastline, has recognized the potential of offshore wind energy, though it is still at a relatively nascent stage compared to the UK and China. India has introduced centralized tenders and land leasing schemes to encourage the private sector's involvement in offshore wind projects. In 2015, India set a target of 5 GW of offshore wind capacity by 2022, which was later updated to 30 GW by 2030. The National Offshore Wind Energy Policy of India (2015) outlines a framework to facilitate the development of offshore wind energy through regulatory support and incentives, including the facilitation of state-owned agencies and public–private partnerships [103]. India has also emphasized the development of local manufacturing capabilities to reduce dependence on imports, similar to China's approach.

Table 3. Comparative analysis of offshore wind scenarios of Bangladesh, India, and Vietnam.

Aspect	Bangladesh (Bay of Bengal)	Vietnam (South China Sea)	India (Gujarat Coast)	China	UK	Key lessons for Bangladesh
Readiness level	Early stage	Moderate stage	Advance stage	Advance stage	Advance stage	Strengthen its policy framework proactively, invest in infrastructure, and engage in international partnerships
Wind resource	6.3–8 m/s (at 160 m); seasonal monsoon winds [15]	7–9 m/s; frequent typhoons [81]	6–7.5 m/s; optimum for hybrid wind–solar farms [5]	5.5–8.5 m/s; suitable for wind power generation [98]	7.88–9.15 m/s, strong consistency in the wind speed [99]	Prioritize cyclone resilience and hybrid systems
Policy framework	No dedicated offshore policy; vague targets [88]	Feed-in tariffs + provincial targets [26]	Centralized tenders + land leasing [5]	Organized; 5-year plans [100]	Offshore Wind Sector Deal; Contracts for Difference (CfD) [5]	Adopt clear sub-targets and tariff guarantees
Technology	Limited local expertise; reliant on imports [6]	Typhoon-proof turbines (e.g. Vestas V174) [27]	Domestic manufacturing (Siemens Gamesa)	Rapidly advancing in manufacturing large wind turbines [100]	Advanced offshore wind technology	Invest in cyclone-resistant designs and local R&D
Socio-economic	Conflicts with fisheries [36]	Compensation for displaced fishers [32]	Community benefit-sharing [5]	Compensation schemes for local communities [100]	Global trendsetter	Implement stakeholder engagement models

Drawing on these international projects, Bangladesh could adopt a hybrid governance framework that combines strategies from proven project models. A dedicated National Offshore Wind Authority should act as a single coordinating body for licensing, environmental assessment, and grid integration, which is similar to the UK's Offshore Wind Delivery Board and India's National Institute of Wind Energy [32, 103]. This authority would streamline decision-making and reduce the fragmentation currently spread across multiple ministries. The authority could administer a CfD-style pricing mechanism to ensure long-term revenue stability and encourage early private investment [5, 101]. To accelerate early-stage projects, temporary feed-in tariffs modeled on Vietnam's approach may attract private developers [102]. These tools, proven in the UK and Vietnam, can provide predictable revenue structures suited to Bangladesh's emerging market conditions. Complementary to these financial instruments, Bangladesh should implement a Marine Spatial Planning Act to align offshore wind zoning with fisheries and shipping corridors, following European practice [41, 42]. Together, these mechanisms could establish a predictable, transparent framework to unlock large-scale offshore wind investment in the Bay of Bengal.

Cyclone-resilient turbine designs for the Bay of Bengal

The Bay of Bengal is highly susceptible to tropical cyclones because of major storms hitting the coastal areas several times annually [57]. These extreme weather events pose structural risks to offshore wind turbines, including

- Extreme wind loads (≥50 m/s gusts) causing blade and tower failure [59].
- Storm surges (up to 10 m) impacting foundation stability [56].
- Saltwater corrosion from high humidity (78.88 avg.) degrading materials [60].

To address these challenges, Bangladesh should comply with the advanced technological strategies being followed in global cyclone-prone regions. Such are as follows:

1) **Turbine design modifications:**

- Tilted or downwind rotors:
  - Reduce wind loading during storms by allowing blades to feather or stall passively [23].
  - Proven effective in Japan's Kamisu Wind Farm (typhoon-resistant turbines survived 60-m/s winds).
- Reinforced towers and foundations:
  - Monopile foundations with thicker steel walls (≥50 mm) and corrosion-resistant coatings (e.g. thermal-sprayed aluminum) for shallow waters (≤40 m) [16, 65].
  - Floating semi-submersibles for deeper waters (≥60 m), leveraging quick-disconnect mooring systems to detach turbines before cyclones [20].

2) **Predictive and operational strategies:**

- Cyclone early-warning systems:
  - Integrate Poisson-distribution models [58] to forecast storm frequency/intensity.
  - Automated shutdown protocols when wind speeds exceed 25 m/s (industry standard).
- Post-storm inspection drones:
  Deploy AI-powered drones for rapid blade/painting damage assessment [68].

3) **Material innovations (humidity-resistant blades):**

- Hydrophobic coatings (e.g. graphene-enhanced epoxy) to prevent water absorption and mold [61].
- Carbon-fiber reinforced polymers for lighter, corrosion-resistant structures [67].

4) **Lessons from global case studies:**

- China's Guangdong Province: uses spar-buoy floating turbines with ballast-adjusted stability for typhoon zones [22].
- Gulf of Mexico (USA): implements TLPs with tendon-based anchoring to resist hurricane loads [30].

Cyclone resilience in Bangladesh should be treated not only as an engineering challenge but also as a systemic operational and policy requirement. Offshore wind projects should follow the IEC 61400-3-2 Class IA standard, which accounts for tropical cyclone gusts >70 m/s and storm surges of up to 10 m [104]. For coastal zones like Cox's Bazar and Sandwip, site selection should favor deeper offshore regions (>40 m) where storm surges have reduced destructive impact. Integrating early-warning data from the Bangladesh Meteorological Department into automated shutdown and pre-emptive control protocols can significantly reduce fatigue and extreme loads on turbines during extreme weather events. Some field studies and technical reports show that coordinated shutdowns and active control strategies often lower peak and fatigue loads by measurable amounts and reduce the risk of storm-related equipment damage [105, 106]. Lessons from Japan's Kamisu wind farm and China's Guangdong projects demonstrate that downwind rotor designs, reinforced monopile foundations, and flexible mooring systems can significantly improve turbine survival under cyclone-level wind speeds [107, 108]. Establishing a joint cyclone-risk monitoring system between BPDB and the Ministry of Disaster Management could further ensure coordinated responses before and after severe weather events. So, the main points stand:

- Prioritize floating turbines (semi-submersibles/TLPs) for depths >40 m.
- Mandate cyclone-resilience certifications (e.g. IEC 61400-1 Class IA) for all projects.
- Establish a regional cyclone database to refine risk models.

Strategic roadmap for offshore wind development in Bangladesh

Offshore wind energy could be a sustainable solution for Bangladesh to address growing energy demand. The heavy reliance on fossil fuel imports can be reduced, which will boost the economy in return, and climate problems can be addressed at the same time. But its success hinges on political will, international collaboration, and sustained investment in R&D. Wind energy can enhance energy security, reduce carbon emissions, and stimulate economic growth. So, a comprehensive offshore wind roadmap to efficiently utilize significant offshore wind resources and ensure a structured transition to renewable energy is a must for Bangladesh. Such a roadmap should outline clear, phased development targets, introduce policy incentives, and incorporate strategic financial models such as PPPs, FDI, and climate funds to support investment and reduce financial risks. For example, the Baltic 1 and Baltic 2 projects in Germany depended heavily on FDI. The European industries have invested billions of dollars to establish the offshore wind farms [109]. Moreover, climate funds, particularly from the GCF, are increasingly being used in countries like India to subsidize the costs of renewable energy projects, including offshore wind [97]. A significant portion of the funding for the massive 30-GW offshore wind capacity expansion plan in the UK comes from a combination of PPPs and climate finance, which has been instrumental in advancing these projects despite high upfront costs [110]. However, the deployment of offshore wind is not easy to implement for a country like Bangladesh. High initial capital costs, grid integration complexities, environmental concerns, and regulatory barriers are some major issues associated with it. A well-structured roadmap based on the lessons and experience gathered from pioneer countries can mitigate these issues by gradual development targets, outlining strategies, introducing policy incentives, and promoting technological advancements. Such a framework is necessary because it would improve coordination among stakeholders, attract both domestic and foreign investments, and ensure environmental sustainability while aligning with national energy policies. A strategic roadmap for offshore wind energy development in Bangladesh is shown in Table 4 below.

Conclusion

Offshore wind energy can be a prospective solution for Bangladesh to achieve sustainable, resilient, and economically beneficial energy generation. If proper planning and strategy are set and the available offshore wind resources are utilized properly, Bangladesh can contribute to global climate change mitigation and reduce its dependency on fossil fuel imports. In order to deploy a successful offshore wind energy project, Bangladesh can look to the policies of the UK, China, Vietnam, and India to shape its approach to offshore wind energy.

This study goes through the offshore wind potential of Bangladesh and highlights its promising prospects. The main challenges, such as high capital costs, technological constraints, and regulatory uncertainties, must be addressed through strategic planning and well-coordinated efforts. First, the government should establish a National Offshore Wind Energy Authority to streamline regulatory processes, coordinate between ministries (Power, Environment, and Shipping), and oversee project implementation. This body could model successful examples like Denmark's Energy Agency, which accelerated offshore wind deployment through centralized decision-making. Second, dedicated R&D funding must be allocated through a Renewable Energy Innovation Fund, which will be used for cyclone-resistant turbine designs and grid integration solutions. Bangladesh can follow the CfD scheme, an approach used by the UK to guarantee long-term pricing stability and attract private investment. So, it is necessary to adopt such institutional and financial frameworks; otherwise, Bangladesh risks falling behind regional peers like Vietnam and India in harnessing its offshore wind resources.

Projects in offshore areas should be done with careful environmental impact assessments, and minimal ecological disruption should be ensured. A comprehensive evaluation of the feasibility of offshore wind projects, aligned with national energy objectives, should be developed. It will be essential in guiding policymakers in formulating effective strategies, and it will also help attract both national and international investors, fostering the growth of the offshore wind sector. The critical knowledge gaps that have been addressed in this paper require investigation to ensure sustainable offshore wind development. First, research is needed on the cumulative ecological impacts of wind farms on the Bay's marine ecosystems, particularly migratory fish patterns and seabird populations. Second, focus should be given to Bangladesh's coastal communities so that their livelihood does not face any obstruction due to offshore projects. For that, socially accepted models should be tailored

Table 4. Strategic roadmap for offshore wind deployment in Bangladesh.

Phase	Timeline	Key actions and milestones	Lead institution(s)/partners	Expected outcomes
Phase 1: Resource assessment and policy setup	2026 Q1–2028 Q4	Dec 2026: complete Bay of Bengal wind mapping Mid-2027: publish techno-economic, environmental, and social feasibility studies 2028: approve national offshore wind policy, secure ADP/World Bank funding	Ministry of Power (MoP) – Bangladesh Power Development Board (BPDB) – Bangladesh Meteorological Department	Wind atlas published – Policy approved by 2028
Phase 2: Pilot projects and capacity building	2029 Q1–2032 Q4	2029: Launch 200-MW demo project 2030: Establish domestic supply chain facility and training center 2031–32: Finalize PPP agreements. Partner with EU/China for tech transfer	BPDB – Private developers (e.g. Summit Power) – Bangladesh Navy (for maritime logistics)	Capacity installed (MW); trained manpower; facility operational
Phase 3: Commercial-scale deployment	2033 Q1–2038 Q4	2035: Reach 2 GW cumulative capacity 2038: 20% hybrid (wind–solar); upgrade grid infrastructure	Power division; PGCB; Ministry of Foreign Affairs; Bangladesh Energy Regulatory Commission (BERC) – Grid Company of Bangladesh – Ministry of Environment	2 GW installed by 2035 – 20% cost reduction via local manufacturing, grid upgrade completed
Phase 4: Regional leadership	2039 Q1–2045 Q4	2040: Establish R&D hub for cyclone-proof turbines for both onshore and offshore 2045: 50% local turbine manufacturing; launch green hydrogen pilots	Bangladesh Council of Scientific & Industrial Research (BCSIR) – Ministry of Foreign Affairs – Private sector	R&D hub operational; local manufacturing (%); hydrogen pilots launched

for offshore communities during the planning phase, built on lessons from conflict resolution in European offshore projects. Finally, floating wind technology feasibility studies should be more focused for deeper waters (>60 m depth) for prospects that can unlock additional capacity beyond the current fixed-bottom technology. Addressing these gaps by prioritizing international collaborations and pilot projects will help strengthen the offshore policy and mitigate risks in Bangladesh's offshore wind sector.

The development of advanced wind turbine technology, coupled with predictive models for natural disasters, will help to mitigate project risks and minimize potential damage caused by extreme weather conditions. For that, establishing a dedicated research and development (R&D) sector for offshore wind technology is crucial for Bangladesh in order to drive innovation in wind turbine efficiency, disaster resilience, and cost reduction. Furthermore, the integration of high-resolution wind mapping tools will facilitate the generation of reliable wind resource data, particularly for deeper areas of the Bay of Bengal. This will expand the scope for offshore wind development, identifying high-potential sites and accelerating the transition toward cleaner energy solutions.

A structured and phased roadmap for offshore wind energy development proposed in this study will be essential for ensuring a systematic and efficient transition to offshore wind energy in Bangladesh. Offshore wind development is prospective for strengthening energy security in Bangladesh. Dynamic government policies, international collaboration, and continuous technological advancements will assist in transforming offshore wind energy from a conceptual possibility into a commercially viable, sustainable energy solution for Bangladesh. A long-term strategic approach could position Bangladesh as a regional leader in offshore wind energy development, fostering economic growth and environmental sustainability.

Author contributions

Sheikh Saimon Ahamed Abir (Conceptualization [lead], Formal analysis [lead], Methodology [lead], Project administration [lead], Resources [lead], Visualization [lead], Writing—original draft [equal], Writing—review & editing [equal]), Md Refaiath Hossain (Formal analysis [supporting], Investigation [supporting], Methodology [supporting], Project administration [supporting], Supervision [supporting], Writing—original draft [equal], Writing—review & editing [equal])

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References

1. Mohazzem, Hossain S, Biswas S, Raihan Uddin M. *Sustainable Energy Transition in Bangladesh: Challenges and Pathways for the Future*. John Wiley and Sons Inc; 2024. https://doi.org/10.1002/eng2.12752
2. Rahman A. Power outages on the rise again. *The Daily Star* Aug. 10, 2024. https://www.thedailystar.net/news/bangladesh/news/power-outages-rise-again-3698866 (6 April 2025, date last accessed).
3. Sarker MT, Al Farid, Alam MJ *et al.* Analysis of the power sector in Bangladesh: current trends, challenges, and future perspectives. *Bull Electr Engin Informatics* 2024;**13**:3862–79. https://doi.org/10.11591/eei.v13i6.7503
4. Bangladesh Power Development Board. "*BPDB Annual Report 2023–2024*"; 2024. https://bpdb.gov.bd/ (20 November 2025, date last accessed).

5. Global Wind Energy Council (GWEC). “GLOBAL WIND REPORT 2024”; 2024. https://www.gwec.net/reports (6 April 2025, date last accessed).
6. Debnath B, Shakur MS, Siraj MT *et al.* Analyzing the factors influencing the wind energy adoption in Bangladesh: a pathway to sustainability for emerging economies. *Energy Strategy Reviews* 2023;**50**:101265. https://doi.org/10.1016/j.esr.2023.101265
7. Abdullah-Al-Mahbub M, Islam ARMT. Sustainable wind energy potential in Sandwip and Kalapara coastal regions of Bangladesh: a way of reducing carbon dioxide emissions. *Heliyon* 2024;**10**:e23982. https://doi.org/10.1016/j.heliyon.2024.e23982
8. Das P, Amin SMM, Lipu MSH *et al.* Assessment of barriers to wind energy development using analytic hierarchy process. *Sustainability* 2023;**15**:15774. https://doi.org/10.3390/su152215774
9. Islam KD, Theppaya T, Ali F *et al.* Wind energy analysis in the coastal region of Bangladesh. *Energies* 2021;**14**:5628. https://doi.org/10.3390/en14185628
10. Das NK, Chakrabartty J, Dey M *et al.* Present energy scenario and future energy mix of Bangladesh. *Energy Strategy Rev* 2020;**32**:100576. https://doi.org/10.1016/j.esr.2020.100576
11. Anjum T. A wind energy potential, progress and challenges in bangladesh: a review. *International Journal of Renewable Energy Resources* 2024;**14**:14–35. https://doi.org/10.22452/ijrer.vol14no1.2
12. Nadi NR, Bingöl F, Badger M. Offshore wind energy estimation in the bay of bengal with satellite wind measurement. *2019 1st International Conference on Advances in Science, Engineering and Robotics Technology (ICASERT), Dhaka, Bangladesh,* 1-8. 2019. https://doi.org/10.1109/ICASERT.2019.8934915
13. Shaikh MA, Chowdhury KMA, Sen S *et al.* Potentiality of wind power generation along the Bangladesh coast. In: *AIP Conference Proceedings*, vol. **1919**, no. 1. Melville, NY, USA: American Institute of Physics Inc.; 2017, p. 020035. https://doi.org/10.1063/1.5018553
14. Hasan M, Dey P, Janefar S *et al.* A critical analysis of wind energy generation potential in different regions of Bangladesh. *Energy Rep* 2024;**11**:2152–73. https://doi.org/10.1016/j.egyr.2024.01.061
15. Joshi P, Patrick D, Aubryn C *et al.* Offshore wind energy fundamentals for bangladesh [Slides]. No. NREL/PR-7A40-89981. National Renewable Energy Laboratory (NREL). Golden, CO, USA; 2024. https://doi.org/10.2172/2394629
16. Wu X, Hu Y, Li Y *et al.* Foundations of offshore wind turbines: a review. *Renew Sust Energ Rev* 2019;**104**:379–93. https://doi.org/10.1016/j.rser.2019.01.012
17. Hsieh CH, Lu LY, Lin CH, Liu JS. Offshore wind energy research trajectory and trends. *2018 Portland International Conference on Management of Engineering and Technology (PICMET)*. Honolulu, HI, USA: IEEE; 2018, 1–5. https://doi.org/10.23919/PICMET.2018.8481999
18. Esteban MD, Diez JJ, López JS *et al.* Why offshore wind energy? *Renew Energy* 2011;**36**:444–50. https://doi.org/10.1016/j.renene.2010.07.009
19. Arshad M, O’Kelly BC. Offshore wind-turbine structures: a review. *Proceedings of the Institution of Civil Engineers - Energy, UK*, vol. **166**, No. 4, pp. 139–52; 2013. https://doi.org/10.1680/ener.12.00019
20. Ma X, Li M, Li W *et al.* Overview of offshore wind power technologies. *Sustainability* 2025;**17**:596. https://doi.org/10.3390/su17020596
21. López-Queija J, Robles E, Jugo J *et al.* Review of control technologies for floating offshore wind turbines. *Renew Sust Energ Rev* 2022;**167**:112787. https://doi.org/10.1016/j.rser.2022.112787
22. Chen J, Kim MH. Review of recent offshore wind turbine research and optimization methodologies in their design. *J Mar Sci Eng* 2022;**10**:28. https://doi.org/10.3390/jmse10010028
23. Zhou B, Zhang Z, Li G *et al.* Review of key technologies for offshore floating wind power generation. *Energies* 2023;**16**:710. https://doi.org/10.3390/en16020710
24. Deng X, Xu W, Xu Y *et al.* Offshore wind power in China: a potential solution to electricity transformation and carbon neutrality. *Fundam Res* 2023;**4**:1206–15. https://doi.org/10.1016/j.fmre.2022.11.008
25. Sherman P, Chen X, Mcelroy M. “*Offshore wind: an opportunity for cost-competitive decarbonization of China’s energy economy*,” 2020;**6**. https://doi.org/10.1126/sciadv.aax9571
26. Fan Q, Wang X, Yuan J *et al.* A review of the development of key technologies for offshore wind power in China. *J Mar Sci Eng* 2022;**10**:929. https://doi.org/10.3390/jmse10070929
27. Wu V. Which three countries will each capture 33% of APAC offshore wind by 2030? *DIGITIMES Asia* 2024. https://www.digitimes.com/news/a20241002VL207/offshore-wind-apac-2030-region-siemens.html (1 May 2025, date last accessed).
28. Aldersey-Williams J, Broadbent ID, Strachan PA. Analysis of United Kingdom offshore wind farm performance using public data: improving the evidence base for policymaking. *Util Policy* 2020;**62**:100985. https://doi.org/10.1016/j.jup.2019.100985
29. WindEurope. “Wind energy in Europe,” 2023. https://windeurope.org/ (6 April 2025, date last accessed).
30. von Krauland, Long Q, Enevoldsen P *et al.* United States offshore wind energy atlas: availability, potential, and economic insights based on wind speeds at different altitudes and thresholds and policy-informed exclusions. *Energy Convers Manag: X* 2023;**20**:100410. https://doi.org/10.1016/j.ecmx.2023.100410
31. Dinh VN, McKeogh E. Offshore wind energy: technology opportunities and challenges. In: Randolph M, Doan D, Tang A, Bui M, Dinh V (eds.), *Proceedings of the 1st Vietnam Symposium on Advances in Offshore Engineering. VSOE 2018. Lecture Notes in Civil Engineering*, vol 18. Singapore: Springer; 2019. https://doi.org/10.1007/978-981-13-2306-5_1
32. World Bank Group. “Key Factors for Successful Development of Offshore Wind in Emerging Markets,” 2021. Available: www.worldbank.org
33. IRENA: Global Atlas. https://globalatlas.irena.org/workspace (19 August 2025, date last accessed).
34. “Global Wind Atlas.”. https://globalwindatlas.info/en/ (19 August 2025, date last accessed).
35. Ministry of Power Energy and Mineral Resources. “Power Master Plan (IEPMP) 2023,” 2023.
36. Hossain MM. Future importance of healthy oceans: ecosystem functions and biodiversity, marine pollution, carbon sequestration, ecosystem goods and services. *J Ocean Coast Econ* 2019;**6**:Article 4. https://doi.org/10.15351/2373-8456.1103
37. Bir J, Golder MR, Al Zobayer MF *et al.* A review on blue economy in Bangladesh: prospects and challenges. *International Journal of Natural and Social Sciences* 2020;**7**:21–29. https://doi.org/10.5281/zenodo.4270719
38. Elayaperumal V, Hermes R, Brown D. An ecosystem based approach to the assessment and governance of the Bay of Bengal Large Marine Ecosystem. *Deep Sea Res 2 Top Stud Oceanogr* May 2019;**163**:87–95. https://doi.org/10.1016/j.dsr2.2019.01.001

39. Saengsupavanich C, Agarwala N, Magdalena I *et al.* Impacts of a growing population on the coastal environment of the Bay of Bengal. *Anthropocene Coasts* 2024;**7**:24. https://doi.org/10.1007/s44218-024-00055-9
40. Islam MS. Perspectives of the coastal and marine fisheries of the Bay of Bengal, Bangladesh. *Ocean Coast Manag* 2003;**46**: 763–96. https://doi.org/10.1016/S0964-5691(03)00064-4
41. Stephenson PJ. 2023 Maritime Spatial Planning in Europe. *Discussion Paper onthe Challenges and Potential Opportunities Around the Colocation of Offshore Wind Energy withMarine Protected Areas*. Berlin, Germany: Report for the Renewables Grid Initiative. https://doi.org/10.13140/RG.2.2.25391.92320
42. Nordquist MH, Moore JN, Chircop A *et al. The Regulation of Continental Shelf Development: Rethinking International Standards*, Vol. **17**. Leiden, Netherlands: Martinus Nijhoff Publishers; 2013
43. Long RJ, Long R. "Offshore wind energy development and ecosystem-based marine management in the EU: are regulatory answers really blowing in the wind?" Available: www.liv.ac.uk/odemm/.
44. Hammar L, Perry D, Gullström M. Offshore wind power for marine conservation. *Open J Mar Sci* 2016;**06**:66–78. https://doi.org/10.4236/ojms.2016.61007
45. Lloret J, Turiel A, Solé J *et al.* Unravelling the ecological impacts of large-scale offshore wind farms in the Mediterranean Sea. *Sci Total Environ* 2022;**824**:153803. https://doi.org/10.1016/j.scitotenv.2022.153803
46. Offshore Wind Facts. https://offshorewindfacts.org (19 August 2025, date last accessed).
47. Dobson T, Lenchine V, Bainbridge S. A review on the interactions between engineering and marine life: key information for engineering professionals. *J Ocean Eng Mar Energy* 2024;**10**: 449–59. https://doi.org/10.1007/s40722-024-00322-4
48. Haslett JR, Garcia-Llorente M, Harrison PA *et al.* Offshore renewable energy and nature conservation: the case of marine tidal turbines in Northern Ireland. *Biodivers Conserv* 2018;**27**:1619–38. https://doi.org/10.1007/s10531-016-1268-6
49. Stranddorf L, Verones F, Olsen SI. Benefits and impacts of offshore wind farms on benthic marine biodiversity in a life cycle assessment context. *Int J Life Cycle Assess* 2025;**30**:2068–85. https://doi.org/10.1007/s11367-025-02504-0
50. Wang L, Wang B, Cen W *et al.* Ecological impacts of the expansion of offshore wind farms on trophic level species of marine food chain. *J Environ Sci* 2024;**139**:226–44. https://doi.org/10.1016/j.jes.2023.05.002
51. Slavik K, Lemmen C, Zhang W *et al.* The large-scale impact of offshore wind farm structures on pelagic primary productivity in the southern North Sea. *Hydrobiologia* 2019;**845**:35–53. https://doi.org/10.1007/s10750-018-3653-5
52. Rawson A, Brito M. Assessing the validity of navigation risk assessments: a study of offshore wind farms in the UK. *Ocean Coast Manag* 2022;**219**:106078. https://doi.org/10.1016/j.ocecoaman.2022.106078
53. Bureau of Ocean Energy Management (BOEM). "Ocean Wind 1 Offshore Wind Farm Final Environmental Impact Statement," May 2023. https://www.boem.gov/renewable-energy/state-activities/ocean-wind-1-final-environmental-impact-statement-feis-commercial (19 August 2025, date last accessed)
54. Chen J-L, Liu H-H, Chuang C-T *et al.* The factors affecting stakeholders' acceptance of offshore wind farms along the western coast of Taiwan: evidence from stakeholders' perceptions. *Ocean Coast Manag* 2015;**109**:40–50. https://doi.org/10.1016/j.ocecoaman.2015.02.012
55. Dantas EJ, Rosa LP, da Silva *et al.* Wind power on the Brazilian Northeast Coast, from the whiff of hope to turbulent convergence: the case of the Galinhos Wind Farms. *Sustainability* 2019;**11**:3802. https://doi.org/10.3390/su11143802
56. Ali A Vulnerability of Bangladesh to climate change and sea level rise through tropical cyclones and storm surges. In: Lin E, Bolhofer WC, (eds.), *Climate Change Vulnerability and Adaptation in Asia and the Pacific: Manila, Philippines, 15–19 January 1996*. Dordrecht: Springer Netherlands, 1996, 171–9.
57. Wahiduzzaman M, Yeasmin A. An assessment of tropical cyclone frequency in the Bay of Bengal and its impact on coastal Bangladesh. *Coasts* 2024;**4**:594–608. https://doi.org/10.3390/coasts4030030
58. Hong L, Möller B. An economic assessment of tropical cyclone risk on offshore wind farms. *Renew Energy* 2012;**44**:180–92. https://doi.org/10.1016/j.renene.2012.01.010
59. Stewart MG. Cyclone damage and temporal changes to building vulnerability and economic risks for residential construction. *J Wind Eng Ind Aerodyn* 2003;**91**:671–91. https://doi.org/10.1016/S0167-6105(02)00462-2
60. Chowdhury MH, Mondal S, Islam J. Modeling and forecasting humidity in Bangladesh: Box-Jenkins approach. *Int J Res GRANTHAALAYAH* 2018;**6**:50–60. https://doi.org/10.29121/granthaalayah.v6.i4.2018.1475
61. Yue W, Xue Y, Liu Y. High humidity aerodynamic effects study on offshore wind turbine airfoil/blade performance through CFD analysis. *Int J Rotating Mach* 2017;**2017**:7570519. https://doi.org/10.1155/2017/7570519
62. Law H, Koutsos V. Leading edge erosion of wind turbines: effect of solid airborne particles and rain on operational wind farms. *Wind Energy* 2020;**23**:1955–65.
63. Brijder R, Hagen CHM, Cortés A *et al.* Review of corrosion monitoring and prognostics in offshore wind turbine structures: current status and feasible approaches. *Front Energy Res* 2022;**10-2022**:991343. https://doi.org/10.3389/fenrg.2022.991343
64. Price SJ, Figueira RB. Corrosion protection systems and fatigue corrosion in offshore wind structures: current status and future perspectives. *Coatings* 2017;**7**:25. https://doi.org/10.3390/coatings7020025
65. Aleem M, Demirci HE, Bhattacharya S *et al.* Innovative foundation design for offshore wind turbines. In: Letcher TM (ed.), *Wind Energy Engineering: A Handbook for Onshore and Offshore Wind Turbines*. Oxford, UK: Elsevier (Academic Press); 2023. 363–81.
66. Firoozi AA, Firoozi AA, Hejazi F. Innovations in wind turbine blade engineering: exploring materials, sustainability, and market dynamics. *Sustainability;* 2024;**16**:8564. https://doi.org/10.3390/su16198564
67. Tong Y, Liu W, Liu X *et al.* Materials design and structural health monitoring of horizontal axis offshore wind turbines: a state-of-the-art review. *Materials* 2025;**18**:329. https://doi.org/10.3390/ma18020329
68. Machado MR, Dutkiewicz M. Wind turbine vibration management: an integrated analysis of existing solutions, products, and open-source developments. *Energy Rep* 2024;**11**:3756–91. https://doi.org/10.1016/j.egyr.2024.03.014
69. Hempel, "Coating Standards: ISO 12944,". https://www.hempel.com/knowledge-center/coating-standards/iso-12944 (28 October 2025, date last accessed).
70. Nordic Steel, "Corrosion class C1, C2, C3, C4 and C5,". https://en.nordicsteel.no/fagartikler/korrosjonsklasse-c1-c2-c3-c4-c5 (28 October 2025, date last accessed).

71. López-Ortega A, Bayón R, Arana JL. Evaluation of protective coatings for high-corrosivity category atmospheres in offshore applications. *Materials* 2019;**12**:1325. https://doi.org/10.3390/ma12081325
72. Safizadeh MR, Wahed MA, Bongs C *et al.* Two-stage air-dehumidification system for the tropics – experimental and theoretical analysis of a lab system. *Energy Procedia* 2014;**48**: 982–90. https://doi.org/10.1016/j.egypro.2014.02.112
73. Troskie B, Toftegaard R, Bonnez K. Corrosivity control inside offshore wind power turbines by combined dehumidification and overpressure. *Mater Corros* 2025;**76**:851–7. https://doi.org/10.1002/maco.202314256
74. Danook SH, Jassim KJ, Hussein AM. The impact of humidity on performance of wind turbine. *Case Stud Therm Eng* 2019;**14**:100456. https://doi.org/10.1016/j.csite.2019.100456
75. Li J, Li G. The utilization of renewable energy and the economic potential of offshore wind power supported by digital finance. *Heliyon* 2014;**10**:e35175. https://doi.org/10.1016/j.heliyon.2024.e35175
76. Chang R, Zhu R, Badger M *et al.* Offshore wind resources assessment from multiple satellite data and WRF modeling over South China Sea. *Remote Sens* 2015;**7**:467–87. https://doi.org/10.3390/rs70100467
77. Ahmad Zaman AA, Hashim FE, Yaakob O. Satellite-based offshore wind energy resource mapping in Malaysia. *J Mar Sci Appl* 2019;**18**:114–21. https://doi.org/10.1007/s11804-019-00066-w
78. de Montera, Berger H, Husson R *et al.* High-resolution offshore wind resource assessment at turbine hub height with Sentinel-1 SAR data and machine learning. *Wind Energy Sci* 2021. https://doi.org/10.5194/wes-2021-35
79. Houghton T, Bell KRW, Doquet M. Offshore transmission for wind: comparing the economic benefits of different offshore network configurations. *Renew Energy* 2016;**94**:268–79. https://doi.org/10.1016/j.renene.2016.03.038
80. Shields M, Cooperman A, Kreider M *et al.* The impacts of developing a port network for floating offshore wind energy on the west coast of the united states. *National Renewable Energy Laboratory (NREL)*. Golden, CO (United States); 2023 Sep 1.
81. IRENA. *Floating Offshore Wind Outlook*. Abu Dhabi: International Renewable Energy Agency; 2024. ISBN: 978-92-9260-612-1.
82. Gao Q, Yuan R, Ertugrul N *et al.* Analysis of energy variability and costs for offshore wind and hybrid power unit with equivalent energy storage system. *Appl Energy* 2023;**342**:121192. https://doi.org/10.1016/j.apenergy.2023.121192
83. Amlashi Hadi O, Lotfizadeh O Life cycle management and probabilistic levelized cost of energy analysis of floating offshore wind farms. In: Kioumarsi Mahdi B, Shafei E, (eds.), *The 1st International Conference on Net-Zero Built Environment*. Cham: Springer Nature Switzerland, 2025, 1749–59.
84. Johnston B, Foley A, Doran J *et al.* Levelised cost of energy, a challenge for offshore wind. *Renew Energy* 2020;**160**:876–85. https://doi.org/10.1016/j.renene.2020.06.030
85. Martinez A, Iglesias G. Levelized cost of energy to evaluate the economic viability of floating offshore wind in the European Atlantic and Mediterranean. *e-Prime - Adv Elec Eng Elec Energy* 2024;**8**:100562. https://doi.org/10.1016/j.prime.2024.100562
86. Röckmann C, Lagerveld S, Stavenuiter J. Operation and Maintenance Costs of Offshore Wind Farms and Potential Multi-use Platforms in the Dutch North Sea. In: Buck BH, Langan R (eds.), *Aquaculture Perspective of Multi-Use Sites in the Open Ocean*. Cham, Switzerland: Springer; 2017, 97–113. ISBN 978-3-319-51159-7.
87. Acharya A. Advent of renewable energy market– understanding critical success factors in PPA model. *Energy Environ Res* 2021;**11**:1. https://doi.org/10.5539/eer.v11n1p1
88. Moazzem KGM, Hridoy MA. Overseas investment in Bangladesh's renewable energy sector: case of Chinese investment. *Centre for Policy Dialogue (CPD) Report* 53. Dhaka, Bangladesh: Centre for Policy Dialogue; 2024.
89. David D, Venkatachalam A. A comparative study on the role of public–private partnerships and green investment banks in boosting low-carbon investments. In: Sachs J, Woo WT, Yoshino N, Taghizadeh-Hesary F (eds.), *Handbook of Green Finance*. Singapore: Springer; 2019, 1–28.
90. Babu MT, Nei H, Kowser MA. Prospects and necessity of wind energy in Bangladesh for the forthcoming future. *J Inst Eng (India): Ser C* 2022;**103**:913–29. https://doi.org/10.1007/s40032-022-00834-8
91. Google Finance, "Conversion rate : BDT to USD,". https://www.google.com/finance (28 October 2025, date last accessed).
92. Jahan MS, Hamim SJ, Bhuiyan MTI *et al.* Comparative cost analysis of VSC-HVDC and HVAC as transmission system for a 50 MW offshore wind farm in Hatiya Island. In *2020 2nd International Conference on Sustainable Technologies for Industry 4.0 (STI)*. Dhaka, Bangladesh: IEEE; 2020, 1–4. https://doi.org/10.1109/STI50764.2020.9350463
93. Amin MT. Prospects of wind energy in Bangladesh. *Int J Adv Ren Energy Res* 2015;**2**:213–8.
94. European Investment Bank, "Bangladesh Renewable Energy Facility.". https://www.eib.org/en/projects/pipelines/all/20220280 (19 August 2025, date last accessed).
95. Memija A. "UK Investor Takes Stake in Hornsea Two Transmission Assets," *offshoreWIND.biz*, 2023.
96. Lacal-Arántegui R. Globalization in the wind energy industry: contribution and economic impact of European companies. *Renew Energy* 2019;**134**:612–28. https://doi.org/10.1016/J.RENENE.2018.10.087
97. Mamat R, Erdiwansyah MF, Ghazali SM *et al.* Strategic framework for overcoming barriers in renewable energy transition: a multi-dimensional review. *Next Energy* 2025;**9**:100414. https://doi.org/10.1016/J.NXENER.2025.100414
98. Tian Y, Kou L, Han Y *et al.* Evaluation of offshore wind power in the China sea. *Energy Explor Exploit* 2021;**39**:014459872199226. https://doi.org/10.1177/0144598721992268
99. Feng Y, Tavner PJ, Long H. Early experiences with UK Round 1 offshore wind farms. *Proc Inst Civil Eng Energy* 2010;**163**:167–81. https://doi.org/10.1680/ener.2010.163.4.167
100. National Development and Reform Commission. *The 13th Five-Year Plan for Renewable Energy Development*. Beijing, China: National Development and Reform Commission, 2016.
101. Noonan M. *UK Offshore Wind: Realising the Sector Deal Opportunity*. United Kingdom: ORE Catapult; 2019.
102. Ha-Duong M. Power system planning in the energy transition era: the case of Vietnam's power development plan 8. *Clim Pol* 2025;**25**:562–77. https://doi.org/10.1080/14693062.2024.2401857
103. Chaurasiya PK, Warudkar V, Ahmed S. Wind energy development and policy in India: a review. *Energy Strategy Rev* 2019;**24**: 342–57. https://doi.org/10.1016/j.esr.2019.04.010
104. H. S. IEC and others. *Wind Energy Generation Systems—Part 3-2: Design Requirements for Floating Offshore Wind Turbines*. Switzerland: International Electrotechnical Commission Geneva, 2019.
105. Annor NK, Ramirez M, Kucukbasol C. Optimization of wind turbine efficiency during severe weather. *Proc Lond Int Conf* 2024;**11**:64–75. https://doi.org/10.31039/PLIC.2024.11.241
106. Liu Y, Ferrari R, van Wingerden. Load reduction for wind turbines: an output-constrained, subspace predictive repetitive control approach. *Wind Energy Sci* 2022;**7**:523–37. https://doi.org/10.5194/wes-7-523-2022

107. Li P, Zhang Y, Wang Z *et al*. Development of design typhoon profile for offshore wind turbine foundation design in Southern China. *Mar Struct* 2023;**92**:103479. https://doi.org/10.1016/j.marstruc.2023.103479
108. Matsunobu T, Inoue S, Tsuji Y *et al.* Seismic design of offshore wind turbine withstands great east Japan earthquake and tsunami. *J Energy Power Eng* 2014;**8**:2039–44.
109. German Federal Ministry for Economic Affairs and Energy (BMWi). *Offshore Wind Energy*. Berlin, Germany: BMWi; February 2015. Available at https://www.bmwi.de (accessed 1 November 2025).
110. "United Kingdom 2024 – Analysis - IEA.". https://www.iea.org/reports/united-kingdom-2024 (1 November 2025, date last accessed).

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