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Winds of Change: Learnings for the Indian Offshore Wind Energy Sector

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CONTENTS

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EXECUTIVE SUMMARY

Highlights

- All of the 40 GW (as of November 2021) of installed wind capacity in India is located onshore. There is potential to harness 70 GW of offshore wind energy off the coasts of Gujarat and Tamil Nadu. A planned demonstration project is being evaluated before committing to larger capacities. Given the time this project would take to develop, India may need to build its first project while simultaneously evaluating higher commitments.
- Offshore wind can become a key part of India's energy mix, but rapid progress must be made on aspects of policy and contracting certainty, low-cost financing, establishment of a local competitive manufacturing base, and supporting infrastructure.
- Our global offshore market review and stakeholder discussions establish that policy and contract volume certainty are key to initiating offshore wind projects. Low-cost financing and greater volume transparency can help reduce tariffs (unit cost), while establishment of local industry depends on the volumes that can be supported by the domestic and export market. Environmental protection and community trust-building efforts are also necessary.
- India can take several steps to increase its offshore wind capacity. In some respects, the examples of other countries can be followed, but in others, India must chart its own path.

The Role of Wind Energy in India's Energy Transition

The global offshore wind energy market has grown by 24 percent annually since 2013 (GWEC 2020), with 36 GW installed by the end of 2020 (GWEC 2021). The market is expected to grow from an estimated US$ 31.8 billion in 2021 to $56.8 billion by 2026, at a compounded annual growth rate of 12.3 percent (BloombergNEF 2021).

Offshore wind can play a prominent role in India's energy transition, especially given the country's target of 500 GW renewable energy (RE) by 2030 across different technologies. The advantages of offshore wind are predominantly due to its higher plant load factors (40–45 percent) when compared with onshore wind (30–35 percent) and ground-mounted solar (20–25 percent) (SECI 2020). The Indian government has set offshore wind targets of 5 GW (by 2022) and 30 GW (by 2030); however, currently there is no offshore wind project in India.

Several interlinked factors need to fall into place if India is to expand its offshore wind market to the levels achieved by, for example, the United Kingdom and Denmark, and the levels that countries such as Taiwan are achieving. These factors include policy and regulation, energy pricing, local content requirement and customization of technology, infrastructure (with an emphasis on ports and grid connectivity), transparency and certainty (availability of data for investors to assess the feasibility of investment and project pipelines), and environmental and social impact assessments.

How India Can Meet Its Offshore Wind Target

In this paper, we consider what India must do to meet its 30 GW offshore wind target. We attempt to answer this question by examining the current state of play—that is, the existing situation in India regarding offshore-wind-related issues, analyzed under categories relevant to India (policy, finance, infrastructure, regulations, and environmental impacts)—and by drawing lessons from successful countries. Our paper does not address these issues at the level of an impact assessment; rather, it lays out and links the various elements required to support offshore wind energy uptake in India, as we believe such an overview is useful at this stage in India's wind energy journey.

Our research is intended to benefit two audiences. The primary audience for this publication is the Ministry of New and Renewable Energy (MNRE), the National Institute of Wind Energy (NIWE), the state energy departments of Gujarat and Tamil Nadu, and investors and developers in the sector. Our paper will also be of interest to the state electricity distribution companies (discoms) of Gujarat and Tamil Nadu, NITI Aayog, and other research groups. The target audience can use the information provided in the paper to understand the current situation in India and formulate the steps that need to be taken by various stakeholders to tap the available offshore wind potential. Further, industry best practices of the leading offshore markets can be understood, and suitable strategies can be devised for India.

Our methodology involved analyzing the peer-reviewed literature, reports, government orders, and policy documents. To compensate for gaps in the literature and in publicly available information, we conducted stakeholder discussions and interviews. The discussions were conducted with RE operators, wind turbine manufacturers, government agencies, global think tanks, and investors through virtual and in-person meetings. We also reviewed case studies and reports on wind energy adoption in other countries to draw lessons for the Indian context.

Key Findings

India has a few building blocks in place that can help the sector expand, but the stakeholders must work together to improve them. For example, on the policy and regulatory front, the National Offshore Wind Energy Policy, 2015, if updated and improved, could serve as a foundation for the sector.

India can take some steps to lower the cost of energy for offshore wind, so that it can be economically included in the energy mix. Bringing down this cost needs time and involves considering multiple elements. Approaches include providing supportive mechanisms such as offshore wind procurement obligation, low-cost debt through subsidies with adequate repayment time frames, and development of domestic manufacturing, thereby achieving economies of scale. The installation platform accounts for a large part of the capital cost of offshore wind. Building large turbines (of 12–15 MW capacity) can reduce the overall capital costs.

India has started considering infrastructural requirements. Recent reports have identified key ports that need to be developed further in Gujarat and Tamil Nadu to support offshore wind activity (FOWIND 2016). Grid interconnections are a key factor in the development of the offshore sector; for onshore renewables, the government is already implementing a Green Energy Corridor scheme.

The RE sector in India currently does not need to obtain prior environmental clearances or environmental permissions from the regulatory authority, but recent research (Forum for the Future et al. 2021; Dharmadhikary 2020) and reactions from affected stakeholders have demonstrated that this situation needs to change.

Recommendations to Increase Offshore Wind Energy Uptake in India

The existing offshore wind energy targets must be reassessed now that the 2022 target of 5 GW is not going to be achieved. This should be done based on pragmatic estimates of the time and cost needed to set up offshore wind facilities. Similarly, coastal states must also be encouraged to develop their own policies to tap offshore wind, a trend that is seen in India in the case of solar energy and onshore wind, and internationally in the United States.

Indian decision-makers need to think deeply about the local content requirements. Although these requirements can boost local job creation and stimulate the economy, any hasty imposition of requirements can increase costs and discourage energy developers. A solution could be to specify the local content requirements based on the offshore wind market capacity and costs, thus ensuring quick and economical project development. Similarly, standards for customization of equipment, installation standards, and Operations and Maintenance practices must be determined by experts taking into account the nature of the seabed, local weather conditions, learnings from other countries, and so on.

Significant progress is required to improve project transparency and certainty. India has chosen to implement a demonstration project. This must be commissioned quickly and the detailed project results and findings shared publicly. Subsequently, India quickly needs to develop a plan for tendering out offshore wind blocks. A strong pipeline will attract investors and bring ancillary benefits, such as the development of local industry.

The government, with MNRE as the nodal ministry, can take responsibility for developing part of the offshore wind power evacuation. This will improve investor confidence as the investment needed will be reduced.

Decision-makers also need to keep in mind the wider possibilities related to industrialization of the coasts coupled with port growth and the opportunities provided by other upcoming sectors such as green hydrogen.

Firm commitments and systems for regulation are necessary to ensure that offshore wind projects do not harm the ecosystem of the local community. The offshore wind sector must lead the way on this.

1. INTRODUCTION AND SCOPE

Oceans cover nearly 70 percent of the earth's surface and affect multiple aspects of life such as food supply, energy, trade and transportation, and rainfall patterns. It is estimated that oceans could sustainably produce six times more food than they produce today, deliver 21 percent of the emission reductions necessary by 2050, provide 40 times more renewable energy (RE) by 2050, and create 12 million new jobs by 2030 (Stuchtey et al. 2020).

Ocean-based RE has significant greenhouse gas (GHG) mitigation potential. Offshore wind is one of the main technologies covered under ocean-based RE, the other being wave and tidal energy (Hoegh-Guldberg et al. 2019).

The Global Offshore Wind Scenario

The offshore wind energy market grew globally by 24 percent every year (in terms of installations) from 2013 to 2020. Bloomberg New Energy Finance (BNEF) recently raised its estimate for the cumulative offshore wind installation capacity by 2035 from 36 GW to 398 GW. This is an 11-fold increase over the period, with contributions by China, the newer markets in Asia, and the United States, in addition to the contribution of the European markets (BloombergNEF 2021). Today, China and Europe are the dominant players, with the rest of world divided into emerging markets and new markets (this includes India) (GWEC 2020). Emerging markets have begun to incorporate offshore wind into their electricity mix, with planned capacity additions and projects in the pipeline. New markets are in the preparatory phase of incorporating offshore wind into their electricity mix. In 2021, 10.7 GW of offshore wind capacity was estimated to come online globally. The pace (up 66 percent from the previous year) and concentration of this growth (72 percent in China alone) are key pointers toward future growth. Offshore wind energy alone has the potential to exceed the total electricity demand in different regions. For example, International Energy Agency (IEA) estimates indicate that the European Union's offshore wind potential is 33.8 million GWh, and the demand for electricity in the bloc in 2018 was 2.9 million GWh (IEA 2019b).

Offshore Wind Scenario in India

India's offshore wind potential is 4.7 million GWh, and its demand for electricity is 1.2 million GWh (IEA 2019b). The ratio of potential to demand is lower than in the EU, but it is clear that offshore wind can contribute to India's energy mix. India currently deploys only onshore wind, with an installed capacity of 40 GW of November 30, 2021 (CEA 2021). Recent reports have estimated that India's market for offshore wind will reach 8 GW by 2035, based on an assessment of project pipelines, long-term targets, and current policies (BloombergNEF 2021).

The Ministry of New and Renewable Energy (MNRE) estimates the potential for offshore wind along the coast of Gujarat and Tamil Nadu at 36 and 35 GW, respectively (MNRE n.d.). However, offshore wind deployment has not progressed. After cabinet approval of the National Offshore Wind Policy in 2015, the MNRE set installed capacity targets of 5 GW by 2022 and 30 GW by 2030. The objectives of the policy are shown in Figure 1.

In 2018, MNRE issued an expression of interest (EOI) to set up a 1 GW offshore wind farm within the Gulf of Khambhat, off the coast of Gujarat. Later it was extended multiple times and revoked after receiving feedback from stakeholders about the high capex and lack of financing support, among other problems (GWEC India 2021).

FOWIND (2015) identified technical solutions and potential zones for offshore wind development through constraint modeling using public domain data. Key constraints considered included technological barriers and spatial conflicts with the fisheries sector. This study was followed by full feasibility studies in 2018 (FOWIND 2018a, 2018b) that identified a sub-zone for setting up demonstration projects. Currently, the National Institute of Wind Energy (NIWE) is preparing to conduct Light Detection and Ranging (LiDAR)-based wind resource assessment studies off the coast of Dhanushkodi, Valinokkam, and Thoothukudi in the Gulf of Mannar. These assessments are needed to validate the model-based wind speed estimations off the coast of Tamil Nadu and to support further planning.

Why Is Offshore Wind Important to India Now?

India has set itself an ambitious target of 500 GW of RE by 2030 (PIB 2019). Currently, RE (excluding Hydro) is dominated by onshore solar and wind, which together constitute 88.59 GW of the installed capacity (CEA 2021). By 2030, the Central Electricity Authority (CEA) projects that the share of wind and solar will be 140 GW and 280 GW, respectively (CEA 2020). Further, the CEA forecasts a shortfall of 47 GW of power capacity between 2022 and 2027 because of India's rapidly rising energy demand, which is estimated to increase at a compounded annual growth rate of 6–7 percent over the next decade.

Figure 1 | **Objectives of MNRE's Offshore Wind Policy 2015**

Explore and promote the deployment of offshore wind farms in the Exclusive Economic Zone (EEZ) of the country, including those under public private partnership	Promote investment in energy infrastructure	Promote spatial planning and management of maritime renewable energy resources in the EEZ of the country through suitable incentives
Achieve energy security	Reduce carbon emissions	Encourage indigenization of offshore wind energy technology
Promote research and development in the offshore wind energy sector	Create skilled manpower and employment in the offshore wind energy sector	Facilitate development of Engineering, Procurement, and Construction (EPC) projects and Operations and Maintenance (O&M) for the offshore wind industry
	Develop coastal infrastructure and supply chains to support heavy construction and fabrication work and O&M activities	

Notes: MNRE = Ministry of New and Renewable Energy.

Sources: MNRE 2015; WRI authors.

Although onshore RE technologies have a theoretical potential that far exceeds the 500 GW target, they require significant tracts of land for installation. In recent years, onshore wind installations have experienced delays or have been canceled due to problems with land acquisition, among other problems. Changes in land availability and land use in Gujarat and Tamil Nadu have impacted project timelines and costs for 93 percent of wind projects awarded under central auction (GWEC and mec+ 2020). Due to their onshore location, plant load factors (PLFs) for these technologies are in the 20–35 percent range (the annual average), whereas for offshore wind they are in the 40–45 percent range. These high PLFs and lower variability make offshore wind's system value comparable to that of baseload technologies (IEA 2019a). Offshore wind also contributes to electricity security and is more stable over time than solar PV. Because of these factors, it is important to consider offshore wind in the energy mix. The cost of power generation from coal power plants is likely to increase as fossil fuel subsidies are phased out and equipment costs increase (with the government mandating the addition of flue-gas desulfurization systems). The Global Wind Energy Council (GWEC) predicts that this will lead to a 9 percent increase in the levelized cost of electricity (LCOE) by 2022 (GWEC and mec+ 2020). This would be favorable for RE options such as offshore wind.

There are potential benefits to blending the use of offshore wind with onshore and solar projects or with green hydrogen projects along the coast for round-the-clock (RTC) renewable electricity, but costs are a constraint and suitable models must be developed.

In 2020, the Solar Energy Corporation of India (SECI) launched a procurement process for a 1.2 GW hybrid wind-solar power project. As offshore wind has higher PLFs and stabilizes the production of onshore wind and solar energy, the feasibility of an offshore-onshore-solar model could be examined to support RTC grid electricity availability. Wind and solar tend to be complementary, where wind can provide the required peak support, resulting in a stable generation profile and smoother output.

The combination of offshore wind and hydrogen is attracting growing interest (IRENA 2021a):

- Offshore wind has one of the highest PLFs, which enhances the electrolyzer utilization rate and consequently increases the hydrogen production capacity.
- Since many major industrial clusters are in coastal areas, offshore wind can meet the demand for the electricity needed to expand industrial operations.
- In contrast to onshore wind and solar, offshore wind reduces land requirements for the development of large-scale green hydrogen projects.

There is currently a strong push toward setting up India's green hydrogen–based economy as many sectors such as steel, cement, and ammonia cannot be decarbonized using direct electrification. To fulfill India's aspiration of becoming one of the cheapest producers of green hydrogen by 2050, MNRE has launched the National Hydrogen Mission in 2021 with a proposed allocation of INR 8 billion ($100 million) to develop pilot projects and set up R&D demonstration projects between 2021 and 2024. The recently launched Green Hydrogen Policy (MoP 2022) provides several incentives for RE supply to green hydrogen projects. This can be an opportunity to explore the offshore wind–green hydrogen coupling further if costs curves are mitigated.

Supportive national policies such as the National Solar Mission, launched in 2010, were instrumental in scaling up solar capacity in India from 25 MW in 2010 to 40 GW by 2021 (PIB 2020). In addition, India has an established manufacturing base for onshore wind equipment (turbines, blades, etc.) that could be exploited for manufacturing offshore equipment. The industry could serve both domestic and near-foreign markets, thereby contributing to the economic growth of the country.

What Does This Paper Aim to Do?

This paper attempts to provide a framework that will enable different stakeholders to tap India's offshore wind potential. This would entail coordinated action on various steps such as creating favorable policies and regulation, energy pricing, local content requirement and customization of the technology, infrastructure (with an emphasis on ports and grid connectivity), transparency and certainty (availability of data for investors to assess the feasibility of investment and the project pipeline), and environmental and social impact assessments. Accordingly, our findings and conclusions are grouped under these categories.

We explore the opportunities and challenges presented by each issue and provide examples, if available, from countries that have successfully begun tapping their offshore wind resources and integrating it into their energy mix. These learnings from other countries are also organized under the same categories that we have identified as relevant to the Indian market.

In-depth analysis of the precise content and form of each of the categories and their subsequent impact on the sector is beyond the scope of this paper and will require further research. We also do not recommend any particular business model, specific regulation, or specific source of finance in this paper.

2. LITERATURE REVIEW, RESEARCH QUESTIONS, AND METHODOLOGY

Methodology

We followed a mixed methodology comprising two elements:

1. We analyzed the publicly available literature, government orders and policy documents, and reports released by other organizations; assessed whether they were relevant to India; and drew appropriate conclusions.
2. We conducted stakeholder discussions on topics and questions where literature is not available, to bridge the information gaps. Those consulted included RE operators, wind turbine manufacturers, government agencies, global think tanks, and investors, through virtual and in-person meetings. We combined the foregoing methodological aspects to arrive at recommendations for India.

For each of the identified issues, we gathered information on the following points relevant to the Indian context:

- A summary of the existing literature and documentation on the topic
- Information gathered from stakeholder consultations
- Learnings from other energy technologies

We subsequently organized the learnings from other countries under individual categories that we identified as relevant to the Indian market. The choice of countries was influenced by the classification made by the wind industry's premier global forum, the GWEC. We identified lessons for India and drafted India-specific recommendations.

What Do We Know So Far?

Offshore wind is a relatively new technology in India. However, literature is available that examines technological developments, the potential for offshore wind, and learnings from the experiences of how non-offshore RE technologies and offshore wind have evolved in India and in other countries.

LITERATURE ON THE GLOBAL SCENARIO

We based our understanding of the global offshore wind energy landscape on the information provided by GWEC (2020). This report gives the market status and outlook for the year 2030 for different offshore markets, categorized into existing, emerging, and new markets based on the number of existing offshore wind projects, those in the pipeline, and targets. Existing markets comprise countries such as the United Kingdom, Germany, Denmark, Netherlands, and China. Emerging markets comprise Taiwan, the United States (Atlantic Coast), Japan, South Korea, and Vietnam, and new markets comprise India, Brazil, Morocco, Philippines, South Africa, Sri Lanka, and Turkey. In our study, India is the only new market that we focus on.

A detailed comparison of offshore wind energy in leading countries such as the United Kingdom, Germany, Denmark, Netherlands, Belgium, and China is provided in *Offshore Wind Outlook 2019* (IEA 2019a). The report compares parameters such as past capacity addition, the share of offshore wind in the energy mix, market size and key players, capacity factors, capital costs and LCOE, and policies. The report also provides an outlook up to 2040 for new markets in the Asia-Pacific region, considering countries such as South Korea, India, and Japan, and briefly discusses the challenges they face. However, key learnings and best practices from the world that are appropriate for India are not discussed.

The regulatory framework of offshore wind in select countries is discussed in Campbell et al. (2021). Current and future projects, policies and regulations, incentives and schemes, grid integration, and offtake arrangements available in Belgium, China, Denmark, France, Germany, India, Japan, South Korea, Netherlands, Poland, Taiwan, United Kingdom, United States, and Vietnam are discussed. The regulatory interventions that facilitated offshore wind in these countries are investigated. The offshore wind energy landscape of specific countries is covered in publications such as Lin et al. (2019), Liu (2019), Munir and Polito (2020), World Bank (2021), and Aegir et al. (2021). We have referred to these studies in the country-specific sections.

LITERATURE ON THE INDIAN SCENARIO

Feasibility and Potential Estimation

FOWIND (2015) is a pre-feasibility study for offshore wind farm development in Gujarat. The report served as a starting point for subsequent full-scale feasibility studies and outlines the potential zones, technical solutions, and strategies needed to initiate offshore wind development in Gujarat. It also briefly explores the cost of energy for such wind projects, taking into consideration the available wind speeds. Environmental issues such as the sensitive marine ecosystem and areas of archaeological significance are also outlined.

FOWIND (2016) focuses on aspects such as the supply chain, port infrastructure, and logistics of setting up offshore wind in Gujarat and Tamil Nadu. This report identifies component specifications, port infrastructure, vessel requirements, and methods for the manufacture, installation, and upkeep of offshore wind farms.

These studies form a sound technical basis for grounding offshore wind in India. However, the lack of uptake until now and the target looming in 2030 warrant a review of the steps that other countries have taken; learnings from them can help accelerate progress in India.

Policies and Regulations

Mani and Dhingra (2013) conducted a perception survey among 100 respondents comprising wind turbine manufacturers, policymakers, project developers and engineering, procurement and construction (EPC) contractors, independent power producers (IPPs), thought leaders, financing institutions, and others (covering captive users, regulatory agencies, discoms, etc.). They derive a set of 21 components or building blocks grouped under five factors to enhance adoption of offshore wind in India. These are fiscal and quota-based incentives, government support, availability of local expertise, an enabling institutional ecosystem, and availability of capital. These factors are similar to the categories used in our study, with some slight modifications. For example, we have explored the different funding sources that could be tapped to expand the sector under Energy Pricing, an integrated approach that combines the form factors "Fiscal and quota-based incentives" and "Availability of capital for investments" that Mani and Dhingra allude to. A critical difference is that their paper was published before India's offshore wind policy was issued in 2015. Our paper also considers developments since then, adds an international perspective, and touches upon the environmental and social obligations of offshore wind project development.

Kota et al. (2015) study offshore wind in the United Kingdom and draw lessons for the United States and India. They recommend that MNRE work with the states for stable, long-term policies; provide clear rules for establishing transmission networks; ensure good Operations and Maintenance (O&M) practices; and understand offshore wind cost structures and explore cost reduction measures. Similar to Mani and Dhingra, the paper by Kota et al. (2015) predates the extant offshore wind policy and does not touch upon the social and environmental aspects of offshore wind.

A report by the Energy Sector Management Assistance Program (ESMAP 2019) assesses the technical potential for offshore wind in India (and seven other countries) and summarizes the transmission network capabilities in Gujarat and Tamil Nadu as well as relevant policies for the sector. These are topics that we have discussed in our paper. The report also describes the linkages between the offshore wind opportunity in Tamil Nadu and developments in northwest Sri Lanka, but this is outside the scope of our paper. The report in general calls for emerging economies to learn from more established markets and adapt the learnings suitably, a principle we have followed and explored in our paper.

Levelized Cost of Energy

FOWIND (2018a) and FOWIND (2018b) report on full-scale feasibility studies for wind farm development off the coasts of Gujarat and Tamil Nadu and cover multiple aspects of offshore development. The expected energy yield and cost of energy are analyzed along with other technical and environmental considerations.

Konar and Ding (n.d) estimate the global net benefit and the benefit-cost ratio, over a 30-year period, of sustainable ocean-based investments in four ocean-based policy interventions: conserving and restoring mangrove habitats, scaling up offshore wind production, decarbonizing the international shipping sector, and increasing the production of sustainably sourced ocean-based proteins. They indicate that the return on investment will increase as the costs of offshore wind energy generation fall. Further, they find that sustainable ocean investments yield benefits amounting to five times more than the costs. They also detail the global LCOE trends of offshore technologies, which could help in developing the basis for financial modeling at the national level and will also be useful for developing comparative studies of the growth of offshore wind.

Environmental and Social Impacts

Kumar et al. (2020) study various factors related to offshore wind, including mapping of potential zones across the Indian coast, environmental impacts, and the impact of climate change on the offshore wind sector. They identify several challenges related to offshore wind and suggest medium- and long-term solutions that can trigger offshore wind development. They propose a set of measures to improve policies and R&D in the country. However, the study does not include interaction with stakeholders on the ground.

Challenges and Opportunities

FOWIND (2017a) focuses on the challenges of integrating the electricity generated by offshore wind farms off the coasts of Gujarat and Tamil Nadu. The report then identifies 12 recommendations organized within 4 themes: deliver existing action plans for onshore transmission networks; fill the gaps in the offshore wind policy related to build-out targets; devise a framework for delivery and ownership with modifications in regulatory codes; and conduct further strategic grid development studies keeping in mind the large offshore wind potential, long-term competence, and capability development. These issues are covered in our report in the transmission section (Sections 3.4 and 5.4).

GWEC India (2021) builds on the above to provide a more updated overview of where the offshore wind sector stands in India. It identifies the current situation and constraints in Tamil Nadu and Gujarat and lists the key challenges to the sector. As the primary global industrial body for wind energy, their recommendations are bound to be useful to the government; but these policy briefs are always best supported by looking at global examples and conducting expert interviews.

Where Are the Knowledge Gaps?

Much of the literature describes the opportunities and challenges of the offshore wind sector in India. Important solutions are also proposed, but we find gaps in the literature. Although the global offshore wind energy landscape is discussed in multiple recent publications, recommendations and best practices for India are lacking. Since there are no offshore wind projects under development in India, gaps in the existing knowledge base can be addressed through stakeholder discussions.

Accordingly, we propose to address the following questions in our research:

- What is the status of offshore-wind-related policy, finance, infrastructure, regulations, and environment impacts in India?
- What successful examples from other countries can be emulated?
- What more needs to be done to ensure the holistic growth of the offshore wind sector?

3. ANALYSIS: THE CURRENT SITUATION

The following factors influence the growth of the offshore wind sector in India. In this chapter, we provide a brief overview of where India stands with respect to each factor.

Policies and Regulations

The guiding policy for offshore wind in India is the National Offshore Wind Energy Policy, 2015 (MNRE 2015). The document specifies India's rights to develop offshore wind projects and conduct R&D in India's exclusive economic zone (EEZ), which extends 200 nautical miles seaward from the baseline. MNRE is the nodal ministry handling RE projects, including offshore wind. It also coordinates with other ministries and departments on tariff and regulatory issues. NIWE has been identified as the nodal agency for the development of offshore wind. The roles of NIWE include inviting proposals for offshore projects, coordinating resources assessment, and helping developers obtain approvals from ministries.

The proposed developmental model is also outlined in the policy document. Directives are also provided that urge the project developers to estimate the impact on the livelihood of local fishing communities and avoid fishing grounds. Discoms are to procure offshore power from developers through power purchase agreements (PPAs). The central transmission utility (CTU) or state transmission utility (STU) is responsible for providing the onshore infrastructure to bring offshore power to land. The final approval for the commissioning the wind farm is to be issued by NIWE after due diligence. Guidelines are also specified for security, decommissioning, monitoring, and fiscal and financial incentives.

Electricity is a concurrent subject under the provisions of List III of the Constitution of India (Government of India 2020), and so both the central and state governments can frame regulations governing it. State governments have also devised technology specific RE policies relevant to their states. For example, Jharkhand has only a solar policy, whereas Karnataka has a solar policy and an overarching RE policy covering other technologies. State-level policies can provide additional incentives for adopting a technology. This is currently a gap in the offshore wind segment. State-specific policies and roadmaps, particularly in the case of Gujarat and Tamil Nadu, can provide further clarity on clearances, incentives, infrastructure, visibility on capacity targets, and who would be the offtaker of offshore wind power. Lastly, setting up offshore wind projects requires clearances and approvals from multiple ministries and government bodies. NIWE is the designated agency to facilitate approvals from different ministries. A list of clearances that NIWE is expected to facilitate across ministries is given in Appendix A. A coordinated and thorough permitting process that ensures certainty regarding timelines and provides clear messaging is necessary.

Energy Pricing

Policymakers generally understand that electricity from offshore wind projects will be more expensive than electricity from onshore projects. A report (NIWE et al. 2021) by the Center of Excellence for Offshore Wind and Renewable Energy (COEFOWRE)—a partnership between MNRE, NIWE, and the Danish Energy Agency (DEA)—on LCOE estimates for the first offshore wind farms indicates that in a P50 scenario[1] the LCOE for offshore wind farms off the Gujarat coast is expected to be INR 15.2/kWh ($0.21/kWh) in 2020–2022 declining to INR 9/kWh ($0.12/kWh) in 2030. Similar values for two sites—B and C—off the coast of Tamil Nadu are INR 10.8/kWh declining to INR 6.4/kWh ($0.09/kWh) by 2030 and INR 14/kWh ($0.19/kWh) declining to INR 8.3/kWh ($0.11/kWh) by 2030, respectively.[2] Our stakeholder discussions indicate that the LCOE estimates for Tamil Nadu and Gujarat for the 2020–22 period are expected to be in the range of INR 7–8/kWh ($0.1/kWh) and INR 11–12/kWh ($0.15/kWh), respectively, assuming imported components with duties waived. Following localization and development of the offshore energy infrastructure, the prices are estimated to drop to INR 3–3.5/kWh over a time frame of about 10–12 years. This could allow for the maturing of an offshore wind ecosystem in India with offshore turbine manufacturing capability, component manufacturing, local supply chains, project execution experience, deployment of larger turbines (>10 MW), and the use of an Indian workforce supporting the price reduction. Other options such as combining offshore wind, onshore wind, and solar could reduce the tariff further. Nevertheless, per-MW installation costs of offshore wind (estimated at INR 140–150 million/MW) are more than double those of onshore wind (estimated at INR 60–65 million/MW) (Parliamentary Standing Committee on Energy 2021).

We have heard varied opinions from industry sources (policy, manufacturers, investors) on the topic of offshore wind pricing. Although some foresee high project costs (compared to onshore wind) in the short term because of the use of smaller turbines (compared to global offshore wind farms) and the allocation of transmission costs to developers, they anticipate that the capex ($/GW) cost will come down as the industry scales beyond 5 GW. On the other hand, other sources are concerned that the capex may not fall with scale beyond a certain limit, given that onshore wind tariffs have remained within a similar range since 2017, despite the availability of larger turbines.

Regarding the offtake of the generated electricity, the National Offshore Wind Energy Policy, 2015, envisages a designated agency or distribution utility or a power company that would sign a PPA with the project developers. Enforceability of the contract will require significant reform of discoms, whose poor financial health has increased the counterparty risks for RE generators and their financial backers. The COEFOWRE blog (COEFOWRE 2021) discusses the need for varied PPA design choices, risk allocation, and de-risking mechanisms to lower projected LCOE estimates. Some such mechanisms are depicted in Figure 2.

The availability of low-cost finance and economies of scale in projects affect the growth of RE. Debt is also a favorable option in the context of low interest rates and an abundance of lenders such as infrastructure debt funds, non-banking financial companies, and the Indian Renewable Energy Development Agency (IREDA). Export credit agencies of original equipment manufacturers (OEMs) can play a significant role by reducing the financing costs associated with doing business internationally. Export credit agencies cover commercial risks, some political risks, and currency risks, allowing offshore wind OEMs to offer competitive terms in the Indian market.

Levels of Customization and Localization

Offshore wind projects call for high levels of customization and planning over their life cycle. The type of foundation used and the technologies employed for construction are site specific and depend heavily on parameters such as the depth of water, type of seabed, ocean currents, climatology, and sea conditions. Geotechnical studies off the coasts of Gujarat and Tamil Nadu have indicated varying soil types (GWEC India 2021) and specific designs for three types of offshore wind farm foundations: monopiles, jacket piles, and gravity-based structures (FOWIND 2015).

Localization of manufacturing facilities for different components of an offshore wind farm, for both domestic use and possible export to neighboring regions, is being considered by policymakers. The job creation potential is significant; for example, the offshore wind projects in Denmark have provided 30,000 jobs (IRENA 2016a). For manufacturing, the extent of localization is determined mainly by the number and/or size of the pipeline of committed projects. The four principal components of offshore development are wind turbines, offshore foundations, electricity infrastructure, and installation vessels and ports (EBTC n.d.). Projects in the range of 0–5 GW will create manufacturing opportunities for secondary steel items, crew transfer vessels, tower platform assemblies, and so on, and a pipeline of more than 30 GW can support full wind turbine generator supply and electrical cables and components for both local use and export (EBTC n.d.). India has a strong local manufacturing presence for onshore wind projects. Companies such as Oil and Natural Gas Corporation of India (ONGC) and Larsen

Figure 2 | **Mechanisms to Reduce Offshore Wind Energy Prices**

Renewable Purchase Obligations (RPOs) mandate a minimum requirement of renewable energy (RE) in the discoms' electricity mix. The Ministry of Power (MoP) has notified the nationwide long-term growth trajectory of RPOs for solar and non-solar technologies until 2022. This can be projected further and can also include RPOs specifically for offshore wind projects.

Feed-in tariffs, coupled with RPOs, could reduce the inherent project risk and stimulate offshore industry growth. Given the financial challenges of Indian discoms, a payment security mechanism could also be considered to mitigate the impact of payment delays.

Corporate Power Purchase Agreements (CPPAs) have been used in various parts of the world, where companies are choosing to transition to RE as part of their sustainability plans. Companies that sign long-term CPPAs with RE providers find this a feasible model to control costs over long periods of time and meet sustainability targets. For offshore wind developers, price visibility from a strong-credit counterparty lowers the overall cost of debt financing. Indian corporates have contracted a total of 17,817 MW of RE as of March 31, 2021, a indicating a willingness to explore and sign CPPAs.

Subsidies have played a key role in the Indian RE ecosystem growth, especially in the case of solar, through viability gap funding and increasingly through production-linked incentives. A similar growth story could be attempted for offshore wind.

Sources: Tyagi et al. 2021. COEFOWRE 2021.

and Toubro (L&T), to name just two, have experience with building and operating offshore oil platforms, which can be adapted for offshore wind farms due to similarities in the platform design in both the sectors. However, this type of localization will have to compete with the existing OEM manufacturing bases in Taiwan, South Korea, and China, which currently cater to the international market. This means that India will have to ensure a large project pipeline to make this viable from a business perspective.

From stakeholder discussions, we learned that the first pilot study would use wind turbines with capacities of 6–12 MW. The locally available manufacturing facilities for onshore wind are equipped for capacities of up to 3 MW and can be augmented for the manufacture of these higher-capacity offshore wind turbines with new lines to accommodate larger components. Stakeholders were of the view that at a minimum a 1.5 GW annual installation pipeline was needed for at least five years to ensure a competitive environment where three credible players would be prepared to begin operations in India. However, there is recognition that India may initially have to rely on imports to kick-start the sector.

We also understand from stakeholder consultations that as the local content requirement (LCR) in Taiwan increased in subsequent bids, there is an apprehension that the low costs seen in the first round of competitive bidding may not be sustainable. Gradually targeted LCRs, as seen in the United Kingdom, Netherlands, and Denmark, facilitated through R&D and capacity-building initiatives could be the approach to emulate.

Logistics and Infrastructure

The components associated with offshore wind energy are larger than their onshore counterparts, with longer blades and support structures. Transportation of these components across land poses a major challenge in India. This can be mitigated by siting the required manufacturing facilities, supply chains, and infrastructure close to ports. The ports must also be large enough, with the required vessel type and availability. The FOWIND study on ports indicates that in Gujarat, Hazira and Pipavav ports are the most promising for upgradation to meet offshore wind requirements. In Tamil Nadu, Thoothukudi port is the best placed; Chennai and Kattupalli ports are secondary choices because of the need to navigate around Sri Lanka to reach the offshore wind sites. The smaller ports can be utilized for O&M purposes (FOWIND 2016).

According to the National Offshore Wind Energy Policy, 2015, the Ministry of Shipping (major ports) and state governments or state maritime boards (minor ports) will provide access to port or port-like facilities near the offshore wind site, with sufficient infrastructure for heavy construction, fabrication, and O&M.

Large capacities of offshore wind energy are expected to come online in the coming years, and careful planning is required to bring the energy ashore and connect it to the grid for onward transmission. Offshore turbines are typically connected through 33/66 kV cables to an offshore substation, which is then linked to an onshore substation using 132–220 kV HVAC cables (FOWIND 2017b), as depicted schematically in Figure 3.

Typically, the responsibility for connectivity from A to B rests with the project developer, whereas responsibility for connectivity from B to C can rest either with the developer or with the transmission system operator (TSO), depending on the market.

According to the MNRE policy, the CTU and/or STU are the agencies responsible for onshore grid power evacuation and connectivity. Connection from the offshore wind farm to the substation on the shore is the responsibility of the developer, which is consistent with the norms being followed for other generating technologies. Prior studies have indicated that achieving onshore grid reinforcement targets under the current Green Energy Corridor (GEC) and large-scale RE integration plans is critical to successfully absorbing offshore wind (FOWIND 2017b). In addition, clear visibility of offshore wind targets and year-wise capacity addition are also important to plan for and build optimal power evacuation capability (FOWIND 2017b).

We learned from stakeholder discussions that the current onshore grid infrastructure will be able to integrate offshore power generation up to about 1 GW of installations, after which the grid will need to be augmented.

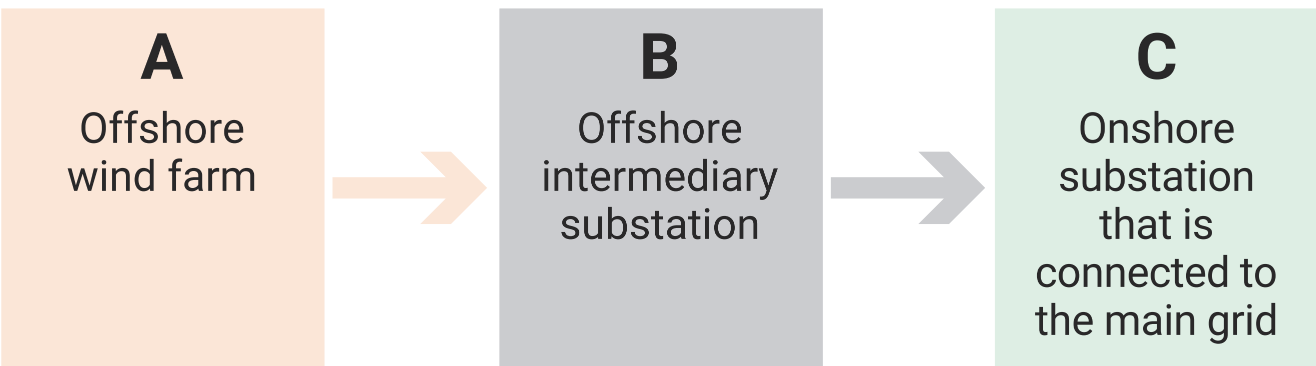
The discussions also suggest that, similar to Germany, India can invest in the creation of a 10 GW power evacuation infrastructure through a plug-and-play model where the offshore power evacuation infrastructure is installed by the government for generators who may be willing to commit to smaller capacities. This would permit faster offshore wind development. It is also prudent to involve the state load dispatch centers, who are responsible for handling the demand and supply of electricity to the state, while planning grid connectivity and offtake of offshore energy.

Transparency and Certainty: Data, Competitive Procurement, and Contracting

Wind potential at the shortlisted offshore sites is estimated from models and simulations, and involves a degree of uncertainty. Estimates needs to be validated through on-site physical measurements to encourage investor confidence and project bankability. Currently, LiDAR-based measurements are underway at locations off the coast of Gujarat and Tamil Nadu, coordinated by MNRE and NIWE. In addition, these offshore wind development zones need to be mapped to include details of shipping lanes, areas for oil exploration, mineral extraction, defense, fishing, and ecologically sensitive areas. We have analyzed reports that assess offshore wind development, particularly off the coast of Gujarat (FOWIND 2018a). Despite the rich data provided, stakeholders believe that precise mapping of exclusion zones and areas of the ocean put to other uses is a major gap (GWEC India 2021). Regularly updated studies for the states of Gujarat and Tamil Nadu are needed now, and future studies for blocks off the coasts of other states will be an essential input for investors before they commit to investing in the sector.

Data availability must be complemented by a robust, competitive procurement process for the identified pipeline of projects. One of the major drivers of the growth of solar energy in India has been the procurement process conducted under the aegis of the Jawaharlal Nehru National Solar Mission by SECI. The process suffered a few setbacks in the past, with some state governments trying to

Figure 3 | **Transmission System Associated with Offshore Wind Energy**



Sources: WRI authors.

renege on contracts that were signed after price discovery (JMK Research & Analytics and IEEFA 2021). This must not be repeated in the offshore wind sector, otherwise future investments in clean energy could be derailed.

It is still early days for the offshore wind sector in India, but lessons can be drawn from the 2018 First Offshore Wind Project of India. Although the initial EOI for setting up a 1 GW offshore wind farm in Gujarat attracted interest from more than 35 national and international players, the high capex, absence of reliable wind data, and lack of viability gap funding (VGF)[3] thwarted the process (GWEC India 2021). Such issues need to be avoided to provide confidence to the investors.

Socioeconomic and Environmental Considerations

Fishing is a major activity that affects the livelihoods of communities and the economy of coastal states, and the impact of offshore projects on fishing and ancillary activities needs to be studied. FOWIND (2015) lists the environmental and socioeconomic laws, rules, and regulations that must be followed for offshore wind farms. There is evidence that offshore turbines can function as artificial reefs, thus supporting biodiversity, but this requires further analysis. In addition, a host of international laws govern the safe transport of dangerous cargo and the prevention of marine pollution.

A rapid environmental impact assessment (EIA) was conducted prior to the EOI of 2018 in Gujarat, but a detailed EIA is necessary to attract responsible investment. The rapid EIA had indicated that many coastal areas of Gujarat are rich in biodiversity and home to fishing activity up to 10 km off the coast. Mangroves and corals are also major ecosystems that need to be managed with care. In the case of Tamil Nadu, detailed studies have not been conducted, but the state is home to a stronger fishing community and equally critical biodiversity resources (GWEC India 2021). Detailed studies should cover all aspects related to offshore wind projects—land- and sea-based impacts—and cover all issues related to site development, commissioning, operation, and decommissioning.

4. OFFSHORE WIND IN OTHER COUNTRIES

GWEC (2020) categorizes the offshore wind markets of different countries as shown in Figure 4.

We have focused on countries listed under existing and emerging markets. Appendix B summarizes the information for each of these countries based on the literature review and stakeholder consultations, where possible. For each country we captured the parameters identified previously: policy and regulation, energy cost, levels of customization and localization, logistics and infrastructure (primarily focusing on ports and grid connectivity[4]), transparency and certainty, and socioeconomic and environmental considerations.

Analysis

The national profiles detailed in Appendix B reveal the following:

Policies and regulations: The existing well-established offshore wind energy markets of Europe are characterized by open and transparent policies and regulations. These markets have clear approval processes for offshore projects with one nodal agency coordinating this process.

Energy pricing: Offshore projects were initially promoted through purchase obligations and subsidies but are now moving toward competitive tenders and schemes such as the Contracts for Difference (CfD) of the United Kingdom, which safeguard the developer against volatile prices. The emerging markets are mainly operating through PPAs and feed-in tariffs (FiTs), and the greater challenges concern regulatory uncertainties, grid infrastructure, and EIAs.

Levels of customization and localization: The existing offshore wind energy markets already boast of leading manufacturers and supporting supply chains. These stakeholders are global leaders in terms of technical expertise and know-how. Local content requirements are often specified for the life of the project, as they are in the United Kingdom. The development of offshore projects has been accompanied by an increase in development and job creation in coastal regions and port cities. Manufacturing facilities for ancillary components are commissioned in inland cities also, as in the case of Germany. Emerging markets are also promoting local content development to strengthen the local economy and supply chains. The existing expertise in sectors such as onshore wind, shipbuilding, and oil and gas is used to develop the offshore ecosystem.

Figure 4 | **Categories of Offshore Wind Markets**

NEW MARKETS
They are in the preparatory phase of incorporating offshore wind into their electricity mix

India, Brazil, Morocco, Philippines, South Africa, Sri Lanka, and Turkey

EMERGING MARKETS
They have begun incorporating offshore wind into their electricity mix and have plans to commission 31 GW of new installations between 2020 and 2024

Taiwan, U.S. Atlantic Coast, Japan, South Korea, and Vietnam

EXISTING MARKETS
They have already incorporated offshore wind into their electricity mix and have a well-defined permitting process and competitive procurement mechanism

United Kingdom, Germany, Denmark, Netherlands, and China

Sources: GWEC 2020.

Ports: Port infrastructure is critical for the commissioning and upkeep of offshore wind projects. Existing markets have dedicated ports that cater to offshore wind. These ports are developed to handle one specific aspect of the offshore project such as installation, O&M, R&D, and decommissioning, as in the case of Denmark. Emerging markets are developing existing ports to handle offshore traffic, setting up manufacturing facilities and logistics close to these ports.

Transmission: In developed offshore markets such as the UK market, the costs of the transmission infrastructure are factored into schemes such as CfD, with the developer being responsible for developing and managing the transmission infrastructure as far as the onshore substation. It was observed that this reduced costs and improved compatibility. In Germany, the responsibility of the transmission to the point of the onshore substation rests with the TSO. The emerging markets are strengthening grid infrastructure to incorporate energy from offshore wind into the energy mix.

Transparency and certainty: There is clear information from most of the existing markets on the status of offshore projects. Plans and time frames are clearly laid out for the execution of new projects and future targets. Projects are awarded to developers through competitive mechanisms, and there is transparency in the proceedings. Defined targets are generally not available from emerging offshore wind market countries such as Japan.

Socioeconomic and environmental considerations: In many of the established European markets, a comprehensive EIA is carried out for large projects. In the case of the United Kingdom, community benefit programs are in place for those impacted by offshore projects. The concerns of the affected communities are addressed in a transparent manner. Information on offshore projects and their impacts are shared with citizens, as in the case of Germany. In emerging markets, policies and compensation mechanisms are formulated taking into consideration regulations and policies, especially for impacted sectors such as fisheries.

Summary

Best practices that helped accelerate the adoption of offshore wind in these countries and those that may be explored for India are listed in Figure 5.

Figure 5 | **Best Practices to Enhance the Offshore Wind Sector**

POLICIES AND REGULATIONS	- Transparency, consistency, and openness of the policy framework are essential - Open, transparent, and consistent tendering mechanisms with well-defined subsidies - The government must revise long-term renewable targets including offshore wind - The central and state governments should work together to achieve offshore targets - Clearances and approval processes should be fast-tracked through a nodal agency - The policy framework must address environment and livelihood concerns - An open business environment and electricity markets without regulatory uncertainties is needed
ENERGY PRICING	- A support mechanism (e.g., Contracts for Difference scheme, feed-in tariffs) that incentivizes the up-front investment costs of offshore project developers while offering protection from volatile wholesale prices is necessary - Competitive tenders effectively reduce cost
LEVELS OF CUSTOMIZATION AND LOCALIZATION	- Develop and strengthen supply chains through local and international partnerships - The government should announce offshore capacity addition targets of sufficient size to attract developers and achieve economies of scale - Existing local industrial and technical expertise must be leveraged - Offshore-specific industries and facilities can be promoted by the government through low-interest loans, grants, public guarantees, and R&D-related incentives
LOGISTICS AND INFRASTRUCTURE	- Existing ports can be modified to handle offshore wind transport requirements - Offshore wind equipment manufacturing clusters can be developed close to the port cities to facilitate offshore wind - If the transmission system operator accepts responsibility for bringing wind energy to shore, confidence increases and costs fall
TRANSPARENCY AND CERTAINTY	- Information about projects under construction, projects in preparation, and plans for integrating offshore wind into the energy mix should be clear and publicly available - Offshore wind zones can be pre-identified and vetted by the government, reducing uncertainties for the project developer
SOCIOECONOMIC AND ENVIRONMENTAL CONSIDERATIONS	- The environmental impacts of offshore wind projects must be considered seriously. Detailed studies involving statutory nature conservation bodies, non-governmental organizations, regulators, developers, and operators will increase the evidence base and understanding of offshore wind projects. They also ensure greater investor confidence and project bankability - In addition to an environmental impact assessment, an environmental monitoring follow-up program can be conducted to study the long-term and cumulative effects on marine life. The concerns of fisheries and fishing communities must be addressed in a fair and transparent fashion. Liaising with fisherfolk and involving them in the development process can improve mutual trust

Sources: WRI authors.

5. CONCLUSION AND WAY FORWARD

Policy and Regulation

India's offshore wind policy framework has ticked a few boxes: setting targets for the country (5 GW by 2022 and 30 GW by 2030) and identifying the nodal agency for procedural and regulatory matters. However, the policy has not been updated to take account of recent developments; for example, the original target for 2022 was 5 GW, but at the time of this writing, no capacity has been added to the grid. Similarly, the Department of Fisheries is not in the list of approving government departments.

Consistently falling RE and storage costs have also opened the possibility of integrating larger shares of RE into the national energy mix, newer technologies such as green hydrogen are emerging, and governing regulations and system operating procedures have also evolved. All these warrant a review of current policy. A longer-term target tends to spur progress and should be considered for the offshore wind sector. Solar power in India witnessed increased interest and progress when the original target of 20 GW was revised to 100 GW by 2022.

Our global review also indicated the advantages of a clear policy in countries such as the United Kingdom, Denmark, Netherlands, Taiwan, the United States, and South Korea. In contrast, countries such as China, Vietnam, and Japan have seen uncertainty in the markets, in part because the required clarity in policies is currently lacking.

India also needs to take advantage of the concurrent nature of electricity, with powers shared between the central and state governments according to the Indian constitution. Offshore wind provides opportunities for the coastal states to facilitate project development. Rajasthan and Andhra Pradesh have recently begun to explore the option of exporting RE from projects set up within their jurisdiction. Similar options need to be explored for offshore wind by Tamil Nadu and Gujarat.

Energy Pricing

Offshore wind tariffs will be very high initially. It is important for India to learn from its solar experience to make the purchase of offshore wind PPAs competitive across the country. Solar energy tariff costs were reduced by a combination of targeted subsidies, regular competitive bids, and contracting structures (with SECI and NTPC as intermediaries) that circumvented the discom finance challenges. Component prices also fell. Tariffs[5] for offshore wind are ultimately determined by a few factors: capex on equipment and the cost of financing (Chawla et al. 2020). O&M is centered around local expertise, and we believe that India should be able to manage this factor.

Recommendations to mitigate high prices include the following:

- Capex reduction: The government can consider providing VGF to project developers. Liberal supplier financing via direct, large orders with OEMs and localization of the domestic offshore industry will also help.
- Profit and loss support: This refers to measures to increase revenues, such as carbon offsets and reduction in costs through scale and large tenders.
- Policy support: Similar to the solar sector, RPOs and FiTs specific to offshore wind can be considered to help expand the sector. Early development and planning of the GEC for offshore wind will help developers by providing them with supporting infrastructure (Chawla et al. 2020).

Potential sources of financing for the above that India can consider are listed in Appendix D.

Even with low costs, the risk of non-payment or late payment by discoms is real. According to data from November 2021 on the Payment Ratification And Analysis in Power (PRAAPTI) portal, discoms owed generation companies a total of about $13.7 billion (INR 1,018 billion) (Government of India 2021). The state discom of Tamil Nadu faces a significant financial problem, exacerbated by the lack of payment guarantees in state auctions, which IPP developers cite as a major hurdle to timely and cost-effective operations. Procurement of electricity from offshore wind projects is likely to suffer because of this. The government could choose from several potential solutions, such as creating a credit enhancement agency to provide a payment security mechanism; nominating SECI and NTPC as procurement agencies that bundle power and then arrive at back-to-back arrangements with discoms (as in the solar sector); or enabling electricity sales to third parties in the event of default. Further, enhanced environmental, social, and governance (ESG) and climate ambitions among Indian companies is driving the adoption of renewable corporate power purchase agreements (CPPAs). The growth of the Indian CPPA market will need to be supported by stable regulatory policies that provide a level playing field for private players and discoms.

Globally, the LCOE of offshore wind declined by 48 percent between 2010 and 2020, from $162/ MWh to $84/ MWh for fixed-bottom offshore wind. This is expected to decline to between $50/MWh and $80/MWh by 2023 (IRENA 2021a). In contrast, the 2019 global average cost for floating offshore wind farms was $160/MWh, nearly double its fixed-bottom counterpart (IRENA 2021a; GWEC 2020).

Offshore wind energy pricing is riding the wave of turbine innovation and GW-level projects. For example, the cost reduction observed in RWE's Sofia Offshore Wind Farm (March 2021) set a record as the cheapest offshore wind project in the United Kingdom. A key factor that reduced the project cost to $2.9 million/MW was the use of 14 MW Siemens Gamesa turbines. A larger turbine capacity decreases the number of turbines required for any given project as it creates spillover cost benefits in other major construction costs such as the foundation and cables. Whether these need to be manufactured in India or imported is an ongoing debate that we cover next.

BUNDLING POWER

One cost reduction option that was tried in the early days of the solar sector in India was the bundling of solar energy with cheaper thermal energy. Our calculations indicate a similar opportunity for offshore wind allied with hybrid RE projects targeting RTC supply. Such projects are beginning to emerge in the Indian market. Their key advantage is to provide an alternative source of electricity in the absence of either sunshine or wind, which is currently provided by coal. Given the economic unviability of utility-scale battery and energy storage in today's market, RTC presents a pathway for transition away from fossil fuels.

Combinations of generation plants may help developers provide higher and more stable generation for the grid; however, their costs and benefits would have to be fully assessed during further research. We have put together a basic model to gauge the economic feasibility of setting up a 1 GW RTC hybrid renewable power facility involving 500 MW of solar, 300 MW of onshore wind, and 200 MW of offshore wind that has the potential to generate an attractive investment opportunity earning 12–15 returns on equity (see Appendix E).

Levels of Customization and Localization

Local content requirements (LCRs) are often specified by countries to promote local job creation, domestic companies, and economic activity. However, strict LCRs in the early stages of sector growth can increase costs and lead times, leading to inefficiencies in project development. They can deter developers. Hence, highly restrictive LCRs should be avoided. Offshore wind sector development in France provides an example. France has suitable offshore locations for tapping wind with a potential estimated at 90 TWh/annum. However, offshore wind projects that were allotted in 2012 have still not been commissioned. Implementation of strict LCRs before the maturity of local supply chains may have been one of the contributory factors (GWEC 2020). Realizing this, France relaxed the LCRs, which resulted in a winning bid of EUR 44/ MWh for the Dunkirk offshore tender by 2019 (GWEC 2020), though other factors were also probably involved.

India need not mandate explicit LCRs. Large potential for offshore wind exists off its coastline, which can support multiple players who will look to set up facilities in India, not just for local supply but also to function as a regional export hub. In addition, the wind sector in India already has 90 percent local content, which will catalyze further localization. It may be desirable to rely on imports for the first one or two tranches of projects to see the kind of technology that can come into India and use that knowledge to improve local manufacturing. Long-term assurances regarding taxes and concessions for these imports are desirable.

Infrastructure

PORTS

Without exception, all the countries that we have studied have made it a priority to develop ports customized to serve offshore wind installations. In India's case, ease of offshore wind construction apart, developing these ports will also be critical as the current road network does not support such construction. In addition, co-location of industries that can use the offshore wind energy can also be planned. The 2016 FOWIND study identified ports in Gujarat and Tamil Nadu that can be used to facilitate offshore wind activities. Although work must commence to upgrade them, India also needs to also look at developing minor ports to support these large ports. In addition, as offshore wind opportunities in other coastal states are assessed, it would be important to evaluate the port opportunities there too.

TRANSMISSION

Transmission costs also play a role in determining the final LCOE. As seen earlier, most successful markets have adopted a model where the TSO funds the connectivity from the offshore substation to the onshore connecting point. GWEC reports that this is a successful model for ensuring a coordinated approach to building offshore wind farms through favorable pricing that transmission companies can access. One recent study analyzed data from the United Kingdom, Denmark, France, and the Netherlands, and clearly demonstrated the role played by the transmission operator in lowering the capex/MW of installed grid connections and the costs of cables and substations (Navigant 2019).

India's policy currently addresses the role of the CTU or STU in developing only the onshore network. Policy thinking should expand to consider a governmental role in developing a portion of the offshore transmission network, which would provide confidence to investors and developers and ultimately reduce the end price.

As new offshore wind capacity with higher PLFs is added to the grid, state and central transmission companies must consider the implications for the existing grid capacity. In the case of onshore wind, India has witnessed project delays due to the mismatch between grid augmentation periods and project gestation periods (Parikh 2020).

HUMAN CAPITAL

Along with the hard infrastructure such as ports and transmission mentioned above, it is important to also develop the skilled workforce that will be necessary to plan, commission, and maintain these projects. NIWE along with the newly formed COEFOWRE would be the agencies best placed to design and conduct the training needed for this. NIWE already conducts training courses on wind turbine testing, wind farm micro siting, resource assessment, and so on, which are also topics relevant for the offshore wind sector.

Transparency and Certainty

To attract widespread interest in project investment, manufacturing, and supply chain development in India, sufficiently ambitious long-term targets are needed. As described earlier, India has offshore wind targets of 5 GW by 2022 and 30 GW by 2030, but the first target will be missed. Now is the right time to revise the targets to provide a more realistic framework for investors.

The feasibility studies for Gujarat and Tamil Nadu need to be broadened (to cover any aspects that may have been missed) and deepened (to explore issues in greater detail). The studies must contribute to developing detailed datasets that can be confidently relied upon by various stakeholders.

It is vital that India set definite milestones and move forward. For instance, there has been discussion about a proposed demonstration project in Dhanushkodi since 2018. The project capacity (currently in the range of 30–40 MW) needs to be significantly enhanced to attract different players; stakeholder consultations reveal that the demonstration project should be at least 400–500 MW in size to generate sufficient interest from developers.

Socioeconomic and Environmental Considerations

If socioeconomic and environmental considerations, which are critical elements of project design, are ignored, offshore wind projects cannot credibly be described as renewable or sustainable. Currently, no EIA has been carried out for the Tamil Nadu locations, and only a summary EIA that does not go into details has been performed for Gujarat. This situation should be rectified as soon as possible. It is essential not only to protect ecosystems (flora and fauna) but also to reassure developers and investors that project development will not be halted or subjected to retroactive requirements later.

At a larger level, RE projects have been exempted from seeking environmental clearances from the government. Many individuals and organizations have argued that this needs to change (Forum for the Future et al. 2021; Dharmadhikary 2020). Offshore wind projects must be required to participate in a transparent environmental and social impact assessment process. In all the international examples that we have studied, environment and social assessments have been given significant importance. They are enshrined in law and have helped speed up project execution.

India has taken initial steps toward growing its offshore wind industry. Progress has not been as rapid as expected, but this can change, as the examples from other countries and the recommendations provided in this section have shown. India can adopt some of the established international practices to enhance trust among the offshore wind development community and expand the sector.

APPENDIX A:
APPROVALS FROM AGENCIES FOR OFFSHORE PROJECTS

National Institute of Wind Energy (NIWE) is responsible for obtaining two stages of clearances from ministries, as shown in Figure A1. This only represents the ministries and agencies under the Union Government, and additional clearances may have to be sought from respective state government departments and agencies. This will be the responsibility of the project developer.

Figure A1 | **Union Government Departments and Approvals Needed for Offshore Wind**

MINISTRY OF ENVIRONMENT FORESTS AND CLIMATE CHANGE (MOEFCC)	- Stage 1: In-principle clearance. - Stage 2: Environment impact assessment (EIA) and Coastal Regulatory Zone (CRZ) clearances.
MINISTRY OF DEFENCE (MOD)	- Stage 1: In-principle clearance. - Stage 2: Clearance related to defence and security aspects, related to the army, navy, air force, Defence Research and Development Organisation (DRDO), and other institutions under the MoD.
MINISTRY OF EXTERNAL AFFAIRS (MEA)	- Stage 1: In-principle clearance. - Stage 2: Clearance for development of offshore wind energy projects within India's maritime zones.
MINISTRY OF HOME AFFAIRS (MHA)	- Stage 1: In-principle clearance. - Stage 2: Clearance regarding deployment of foreign nationals in offshore wind energy blocks.
MINISTRY OF CIVIL AVIATION (MCA)	- Only Stage 2: Clearance for construction near aviation radars/aerodromes. No clearance/No Objection Certificate (NOC) required for other locations.
MINISTRY OF PETROLEUM & NATURAL GAS (MOPNG)	- Only Stage 2: Clearance for offshore wind power installations proposed in oil and gas blocks. NOC for construction outside the offshore oil and gas blocks.
MINISTRY OF SHIPPING (MOS)	- Only Stage 2: Clearance for projects near major ports. NOC to operate away from shipping lanes.
DEPARTMENT OF SPACE (DOS)	- Only Stage 2: Clearance from security angle with regard to Department of Space installations and for minimum safety distance to be maintained from such installations.
DEPARTMENT OF TELECOMMUNICATIONS (DOT)	- Only Stage 2: NOC to operate outside subsea communication cable zones.
MINISTRY OF MINES (MOM)	- NOC to operate outside mining zones.

Sources: MNRE 2015.

APPENDIX B: OFFSHORE WIND MARKET IN SELECT COUNTRIES

The current situation in 10 select countries is discussed below. The existing markets considered include United Kingdom, Germany, Denmark, Netherlands, and China. Emerging markets including Taiwan, United States, Japan, South Korea, and Vietnam (GWEC 2020).

Table B1 | **United Kingdom**

POLICIES AND REGULATIONS	• According to the ITA (2021), one of the key factors powering the growth of the UK offshore wind market is its openness and transparency. The Crown Estate[a] owns the seabed and is responsible for leasing it for offshore wind development through a competitive process. Once the lease process is completed, the developer must obtain a Development Consent Order from the Planning Inspectorate, permissions from local authorities, and a generation license. For the last item, the Department for Business, Energy and Industrial Strategy (BEIS) and the Office of Gas and Electricity Markets are the key entities.
ENERGY PRICING	• The United Kingdom introduced the Renewables Obligation subsidy scheme in 2002 for large renewable projects. This supported the development of offshore wind until 2017, up to a capacity of 5 GW. In 2013, this mechanism was replaced by the Contract for Difference (CfD) (https://corporatefinanceinstitute.com/resources/knowledge/finance/contract-for-difference-cfd/) scheme that incentivized the up-front investment costs of offshore project developers while offering protection from volatile wholesale prices. This support scheme is still in force, ensuring continued interest in the offshore renewables sector. Not only has it limited the requirement for subsidies but it has also delivered a high volume of projects with falling prices—from 154 Euros/MWh (INR 13.4/kWh) in a 2015 auction to 46 Euros/MWh (INR 4/kWh) in a 2019 auction. This model is now being adopted in other markets such as Poland, Denmark, and Germany (GWEC 2020).
LEVELS OF CUSTOMIZATION AND LOCALIZATION	• In 2019, the UK government released the Offshore Wind Sector Deal to consolidate the United Kingdom's leadership in the sector and maximize advantages for the UK industry (BEIS 2019). It set a target of 60 percent UK-made products to be utilized over the lifetime of a wind farm to be commissioned from 2030. To achieve this, the UK government has launched the Offshore Wind Growth Partnership. This scheme supports the development of "productive, competitive and export-oriented supply chains." The sector is also targeting an increase in exports to GBP 2.6 billion per annum by 2030. • From the first CfD round in 2015, the levelized costs of energy fell by 30 percent in 2017 and by 66 percent in 2019 compared to the first-round costs. Further capacity additions and ambitious targets set for the future will ensure further price reductions. Factors such as increased competition, economies of scale, and efficient supply chains supported through the right policies are contributing factors (GWEC 2020).
PORTS	• The United Kingdom's Ten Point Plan for a Green Industrial Revolution emphasizes the development of offshore wind. The government has committed to investing GBP 160 million in modern ports and manufacturing infrastructure (BEIS 2020). More recently, the government announced the investment of GBP 132 million in the construction of two offshore wind ports, which are expected to accommodate up to seven manufacturers.
TRANSMISSION	• Developers pay for the connection from the offshore wind farm to the onshore substation. The responsibility for grid connection is specified in the tender of the CfD agreement. Studies have found that this method reduces costs and improves the compatibility of the offshore-onshore transmission infrastructure (GWEC 2020).

Table B1 | **United Kingdom (Cont.)**

TRANSPARENCY AND CERTAINTY	• Cost reductions reflect a combination of government policy and industry innovation. Government policy reduced risk and lowered finance costs (e.g., by providing long-term contracts for renewable power). Industry innovation benefited from learning by doing, making the most of economies of scale and falling financing costs as confidence in the new technologies grew with their deployment. The Green Investment Bank was set up to plug potential gaps in financing low-carbon technologies such as offshore wind and to "crowd in" private investors, while ensuring healthy commercial returns.
SOCIOECONOMIC AND ENVIRONMENTAL CONSIDERATIONS	• The UK government's strategy indicates that the environmental impacts of offshore wind farms have been considered seriously. The Crown Estate has committed to establishing a "strategic enabling actions programme" that is expected to run in parallel with new lease approvals and development. This program is expected to consist of a partnership involving statutory nature conservation bodies, non-governmental organizations, regulators, developers, and operators, to increase the evidence base and better understand offshore wind projects. It will look at the impacts on both marine and onshore areas (BEIS 2019). • There is also a recognition of the support needed from local communities and a commitment to invest in projects that benefit local communities. Vattenfall, for instance, studied the social impacts of offshore wind on the quality of life, housing, and local industries (such as fisheries) and suggested Community Benefit Agreements as one of the means of alleviating social concerns (Glasson et al. 2020). Addressing the concerns of fisheries in the United Kingdom in a fair and transparent fashion was one of the key steps that helped move the offshore wind sector forward. Fishery liaisons were also established to improve trust between developers and fishers (Haggett et al. 2020).

Note: a Further information on the United Kingdom's Crown Estate can be found at https://www.thecrownestate.co.uk/.

Table B2 | **Germany**

POLICIES AND REGULATIONS	• Germany is a renowned industrial powerhouse across different industrial sectors, and offshore wind is no exception. This growth has been facilitated through incentives aimed at reducing investment costs or operating costs: low-interest loans, grants, public guarantees, and labor- and R&D-related incentives (WWEA 2018b). Germany's offshore wind installations are mandated to operate in locations far off the coast to protect mudflats and address concerns about landscape changes due to wind turbines. This places them outside the territorial waters of its exclusive economic zone (EEZ). For projects in this area, the Federal Maritime and Hydrographic Agency is responsible for approvals after a detailed assessment of socioeconomic (fisheries mainly), environmental, military, and shipping impacts. If any installations are located in territorial waters, the local state authority is responsible for clearances (BWE n.d.). The amended Offshore Wind Energy Act (OWEA) of December 2020 raised the offshore wind target for the country from 15 GW to 20 GW by 2030 and to 40 GW by 2040 (Deutsche WindGuard GmbH 2020).
ENERGY PRICING	• Feed-in tariffs (FiTs) and market premiums were introduced through the German Renewable Energy Act (EEG) of April 2000. Following multiple iterations, the EEG reform of 2017 made it compulsory for offshore wind projects to participate in tariff auctions. The auction saw two zero-subsidy projects. However, following a review, Germany too has decided to adopt the CfD model.
LEVELS OF CUSTOMIZATION AND LOCALIZATION	• The development of offshore wind in Germany has encouraged new wind turbine manufacturing facilities in coastal regions and ports along the North Sea. Ports such as Bremerhaven and Cuxhaven provide shipping services to support the offshore wind industry along with manufacturing facilities for foundation systems and turbines. Manufacturing facilities for ancillary components such as generators, gearboxes, and bearings have expanded to inland cities, resulting in development and job creation.
PORTS	• To facilitate the installation of offshore wind assets, Germany has adapted ports along the North Sea and Baltic Sea. Measures undertaken include expanding the port area to accommodate plant and component manufacturers, and creation of heavy-duty terminals and berths for the special ships that are needed for construction and O&M (BWE n.d.).
TRANSMISSION	• The responsibility for connection from point B to C rests with the transmission system operator (TSO). As of December 2020, about 8.2 GW of grid connection capacity had been commissioned, and some of it was also being used by existing offshore plants. Several projects have been identified for commissioning, either in the grid development plan or in the offshore wind site development plan. Available estimates indicate close to 29 GW of connection capacity in the North Sea and nearly 2 GW in the Baltic Sea. This closely corresponds to the targets set out in the OWEA (Deutsche WindGuard GmbH 2020).
TRANSPARENCY AND CERTAINTY	• By the end of 2020, Germany had 7,700 MW of operational offshore wind. With the country moving toward a new mechanism of CfD, capacity additions are expected from 2022 onward. An annual run rate of 9.2 GW is expected to meet the 2030 target, and the industry seems optimistic about achieving the targets given that potential sites have been identified in the spatial plans for government agencies (Deutsche WindGuard GmbH 2020).
SOCIOECONOMIC AND ENVIRONMENTAL CONSIDERATIONS	• The Federal Nature Conservation Act (BNatSchG) is the key governing legislation, with additional protection provided by regional planning guidelines that prevent the development of wind farms in vulnerable locations. Environmental impact assessments (EIAs) are mandatory for projects that have more than 20 turbines. Smaller projects need an EIA only if the authorities require it. In addition, there are requirements for sharing information with citizens (WWEA 2018b).

Table B3 | **Denmark**

POLICIES AND REGULATIONS	• Denmark has many laws that promote renewable energy, the most important of which are the Electricity Supply Act and the Promotion of Renewable Energy Act, the Act on Energinet.dk, the Act on the Carbon Duty Tax on Certain Energy Products, the Electricity Tax Act, the VAT Act, and the Planning Act. In addition, from the year 2000 onward, several rules related to subsidies have been put in place, for both onshore and offshore wind projects (WWEA 2018a). • The Danish Energy Agreement of 2012 mandated 500 MW of nearshore and 1,000 MW of offshore projects in the period 2014 to 2020. The target has been increased by 6,800 MW and is expected to be achieved by 2030 (WWEA 2018a; Vilnes 2020). • The Danish Energy Agency (DEA) is the "one stop shop" that coordinates various approvals and processes for offshore wind projects. Three primary licenses—to conduct preliminary investigations, to install offshore wind turbines, and to produce electricity—must be obtained in sequence (WWEA 2018a).
ENERGY PRICING	• Denmark initially supported renewable energy (RE) projects through Public Service Obligation (PSO) tariffs: varying combinations of FiTs and subsidies were used. In 2016, plans were made to phase out PSOs by 2022 and finance projects through the national budget. In 2019, the CfD model was adopted for the development of new projects, with subsidies in the form of premiums for 20 years, an example being the Thor offshore wind project being developed by RWE in Denmark (GWEC 2020).
LEVELS OF CUSTOMIZATION AND LOCALIZATION	• Denmark is a good example of the industrial growth that is possible when concentrated and sustained efforts are put into wind energy. The long-term alignment with wind has seen Denmark transform into a global expert in the field of offshore wind energy, home to some of the leading wind turbine OEMs, offshore wind farm developers, and supporting industrial clusters. The key driver for this has been the government investment in R&D and the development of testing and certification center. As a result, the Denmark wind ecosystem houses more than 500 suppliers over the entire supply chain. The wind cluster supports more than 30,000 jobs and contributes about 4 percent to the GDP (GWEC 2020).
PORTS	• Denmark has several ports that play various supporting roles in offshore wind. There are specialized ports for the installation of offshore wind farms: Ronne for O&M, Hvide Sande for research and testing, Aalborg for decommissioning, and Nyborg and the multipurpose Esbjerg port that combines the functions of pre-assembly, installation, and O&M. It also provides feeder services to other ports in Denmark and other countries. • Esbjerg is also cited as an example of the energy transformation in Denmark. It was once Denmark's leading service hub for the oil and gas sector but has since transformed into a global hub for offshore wind. Another achievement to Esbjerg's credit is its role in enabling local companies to gradually move "from oil and gas to a new sector; pursue growth in new markets and diversify their business strategy, also well beyond Denmark's borders. As a result, Esbjerg is now home to around 250 suppliers to the global offshore wind sector…" (QBIS Consulting 2020).
TRANSMISSION	• Up to 2018, the responsibility for connectivity from points B to C was with the TSO. Since then, the responsibility has been transferred to the developers, with the costs being factored into the CfD agreement.

Table B3 | **Denmark (Cont.)**

TRANSPARENCY AND CERTAINTY	• Competition has been incorporated into the procurement process. As DEA is the contracting authority and has the integrated responsibility for planning future offshore projects, EIAs, other approvals, and calls for tenders, the confusion that can arise from having to deal with multiple agencies is eliminated. In addition, targets have been announced well in advance, giving developers adequate visibility.
SOCIOECONOMIC AND ENVIRONMENTAL CONSIDERATIONS	• Currently all Danish offshore wind energy projects are required to conduct an EIA. These cover the installation site, the export grid route, and the onshore power evacuation facilities. In addition, Denmark has also commissioned an "environmental monitoring follow-up programme" that focuses on long-term and cumulative effects on marine fauna (Danish Energy Agency 2019). • Fisheries are protected under the Danish Fisheries Act and fisherfolk who operate in the area assigned to an offshore wind farm must be compensated. The project developer is expected to negotiate with the fisherfolk, and the licensing process is completed only after an agreement is reached with the affected parties (Danish Energy Agency 2018).

Table B4 | **The Netherlands**

POLICIES AND REGULATIONS	• Offshore wind has been recognized as a key enabler for the Netherlands to achieve its 2050 goal of all energy coming from RE sources. The total installed capacity of offshore wind power in the Netherlands was about 2.5 GW in 2021 and is expected increase to at least 4.5 GW by 2023, which would be in line with the commitments made in the Energy Agreement for Sustainable Growth. The 2030 target for offshore wind in the country is 11 GW with a further outlook of 38–72 GW by 2050. The national government through its various ministries is the key body in charge of planning and implementing offshore wind projects.
ENERGY PRICING	• Between 2003 and 2007, the Netherlands introduced FiT and reduced ecotax as part of its Environmental Quality of Electricity Production subsidy scheme for the period 2003–07. Due to high costs, this was replaced by the Sustainable Energy Incentive Scheme (SDE) in 2008 with the aim of developing 450 MW of offshore wind. Since the progress was slow, premium FiTs were introduced in 2011 targeting 4.5 GW of offshore wind capacity by 2023. This was the SDE+ scheme and introduced tendering with subsidies, providing much-needed risk mitigation and guarantees to project developers. The first SDE+ tender in 2017 resulted in cost reductions of 40 percent. There was experimentation with different tenders that did and did not have subsidy elements built into them. However, it must be kept in mind that these tenders are highly site specific, requiring the right market conditions for their successful implementation (GWEC 2020).
LEVELS OF CUSTOMIZATION AND LOCALIZATION	• In the offshore wind sector, the Netherlands is estimated to be very strong in wind energy R&D, offshore design and engineering, and offshore construction and installation; strong in wind turbine design and wind farm development and exploitation; average in offshore maintenance; and weak in wind turbine production. Therefore, the emphasis is on attracting entrepreneurs and companies to set up facilities to help strengthen the country in the areas in which it is average or weak (TKI-Energie Foundation n.d.).
PORTS	• Ports in the Netherlands border all offshore wind farms in different stages of planning, construction, or operation across the United Kingdom, Germany, Belgium, Denmark, and the Netherlands. Multiple ports such as Amsterdam (production, import-export, O&M), Den Helder (O&M), Eemshaven-Groningen (base, O&M), Harlingen (O&M), Rotterdam (base, production, import, export, supply, and O&M), Vlissingen-Zeeland (base), and Ijmuiden (base, import-export, and O&M) offer a full suite of services to developers to help them plan for installation or operation of offshore wind farms (TKI-Energie Foundation n.d.).
TRANSMISSION	• Netherlands' offshore grid operator, TenneT, is responsible for connecting wind farms to the onshore power grid. TenneT is expected to construct five standardized platforms with a capacity of 700 MW each within the wind farm zones. Developers can directly connect to these platforms and lower their costs due to economies of scale (Government of Netherlands n.d.a; WWEA 2018c).

Table B4 | **The Netherlands (Cont.)**

TRANSPARENCY AND CERTAINTY	• Our research indicates that there is clear visibility of, and information about, projects under construction, projects under preparation, and plans for integrating offshore wind after 2030 in line with the policy pronouncements (RVO n.d.).
SOCIOECONOMIC AND ENVIRONMENTAL CONSIDERATIONS	• Offshore wind projects are classified under Annex II of the EIA directive of the European Union, which leaves the decision on whether an EIA is needed or not to the concerned authority. The Offshore Wind Act in Netherlands makes it mandatory for offshore wind projects to conduct an EIA (Government of Netherlands n.d.b). • Before 2015, fisheries were prohibited in wind farms in the Dutch EEZ. In 2015, the government proposed draft regulations that would permit fisherfolk to traverse the wind farm safety zones with adequate precautions: for example, bottom-disturbing fishing gear was to be carried over the waterline. Similarly, professional fishing was permitted using only specific fishing gear specified by the government. These regulations were piloted in the vicinity of three windfarms, but success proved elusive due to concerns over sharing of the costs to align the offshore facilities with the new regulations; compensation to windfarms for damage due to equipment; and compensation for loss of work time to deal with any potential third-party safety issues. In response, an independent review was conducted. It recommended that the 2015 regulations be followed with additional risk assessments for any lost fishing gear. These new regulations were piloted in 2018 with an initial (but automatically renewed) duration of 2 years. The government, however, is of the view that a corridor enabling the transit of vessels up to 45 meters is the long-term solution. These are expected to be available in projects to be commissioned by 2023 (EU MSP 2019).

Table B5 | **United States**

POLICIES AND REGULATIONS	• The United States currently has about 30 MW of installed offshore capacity, with more projects in the pipeline. Projects totaling 10.6 GW and 20.6 GW are expected to come online by 2026 and 2030, respectively. The capacity is expected to reach nearly 40 GW by 2040, with investments totaling $100 billion (IEA 2019a). A combination of federal support and state-level targets supports this growth. The Bureau of Ocean Energy Management (BOEM) under the U.S. Department of the Interior is responsible for the development of offshore resources at the federal level, based on the Energy Policy Act of 2005. BOEM issued 16 leases in 2019 for the development of commercial offshore wind projects with a combined capacity of 21 GW. Further lease sales are expected for other offshore locations. At the state level, strong targets and policies facilitate growth. The states on the East Coast are primarily driving offshore capacity additions through specific targets (GWEC 2020).
ENERGY PRICING	• The decline in costs for offshore projects in the United States is expected to mirror global trends. Globally, the up-front costs are projected to decrease by over 40 percent to $2500/kW (INR 18.45 crore/MW) by 2030 and to $1900/kW (INR 14.01 crore/MW) by 2040. The cost reduction would be facilitated by maturation of the offshore ecosystem and development of economies of scale (IEA 2019a). Incentives are provided to developers through federal tax credits. • States such as New York are also using their planning capabilities to call for competitive tenders to significantly reduce costs (Kauffman and Sandalow 2020).
LEVELS OF CUSTOMIZATION AND LOCALIZATION	• The United States is still in the early stages of setting up local supply chains for projects. An announcement from the White House mentioned a massive plan to consolidate supply chain benefits by meeting the 2030 target. These include setting up 1–2 new U.S. factories for every major windfarm component: turbine nacelles, blades, towers, foundations, and subsea cables. The plan also envisages the production of 7 million tons of steel and construction of 4–6 specialized turbine installation vessels in U.S. shipyards. The Department of Energy's (DOE) Loan Program Office has also announced a $3 billion debt facility to support the industry (The White House 2021).
PORTS	• Offshore activities are concentrated along the East Coast in clusters such as Maine, Connecticut, Massachusetts, New York, New Jersey, Delaware, Maryland, Virginia, and North Carolina. Nearby ports could be used for offshore wind activities such as New Bedford in Massachusetts, Tradepoint Atlantic in Maryland, New London and Bridgeport in Connecticut, Port of Providence in Rhode Island, Port of Virginia in south-eastern Virginia, and the recently planned New Jersey Wind Port. The ports should be able to handle oversized offshore components with respect to aspects such as heavy-lift capacity, ship access, overhead clearances, channel draft, and physical laydown space. In view of the above, 12 projects have been announced since 2017 for developing port infrastructure to handle offshore wind activity (ABS 2021).
TRANSMISSION	• Transmission infrastructure for offshore wind in the United States is currently built and operated by generators under the supervision of the Federal Electricity Regulatory Commission (FERC). Since 2020, discussions have been underway to transition to a TSO-led process where common infrastructure is created for developers (FERC 2021; St. John 2020).
TRANSPARENCY AND CERTAINTY	• The regulatory process is perceived to be complex and often varies from state to state. Even the issuance of leases by BOEM is a four-step process, with the first step only granting the lessee permissions to develop its site development plans. The plans need to be scrutinized and approved before the developer can move on to subsequent steps involving technical and environmental reviews. The lessee is also expected to decommission facilities at the end of the lease period.
SOCIOECONOMIC AND ENVIRONMENTAL CONSIDERATIONS	• The U.S. government has sanctioned $1 million in grant funding to conduct community-focused research to understand the impact of offshore wind farms on local communities and fisherfolk. However, individual projects have also been conducting such research. • BOEM has also sanctioned Environment Impact Statement studies for three offshore wind projects up to March 2021. It also anticipates reviewing up to 10 more projects going forward (The White House 2021). The DOE has also sanctioned the largest ecological study in the mid-Atlantic to obtain a complete picture of suitable sites that could be used in the permitting and approval processes (DOE n.d.).

Table B6 | **South Korea**

POLICIES AND REGULATIONS	• Development in offshore wind in South Korea was initiated with the commissioning of the 30 MW Tamra offshore wind farm in 2016. However, the progress since then has been slow due to environmental and livelihood concerns relating to fishing, delays with the approval process, and low FiTs. As of June 2020, the installed offshore capacity stood at 132.5 MW. To mitigate the above issues and accelerate the uptake of renewables, the country adopted the Green New Deal, with a pledge to achieve net zero by 2050. The Third Energy Plan of 2019 set a target of generating 20 percent of electricity from renewable sources by 2030 and forms the current policy base for renewable development in the country (GWEC 2020). The existing policies have set targets of 12 GW of offshore wind by 2030 for achieving the renewable targets set by the Third Energy Plan (Aegir et al. 2021).
ENERGY PRICING	• For offshore wind projects coming online in 2020, the capital costs excluding transmission are in the range of $4,000–5,000/kW (INR 295.1 million/MW–INR 369 million/MW). This is expected to fall below the $4000/kW mark for projects being commissioned in 2023. The O&M costs are also expected to fall by 40 percent by 2040 (IEA 2019a). For projects being commissioned in 2026, the LCOE for fixed-bottom farms is computed at 91–95 EUR/MWh (INR 7.94/kWh–INR 8.29/kWh) (domestic manufacturing) and for floating sites at 98–101 EUR/MWh (INR 8.55/kWh–INR 8.81/kWh) (partnerships model) and 116–120 EUR/MWh (INR 10.12/kWh–INR 10.47/kWh) (domestic manufacturing model) (Aegir et al. 2021). The LCOE for offshore wind is expected to reach parity with onshore wind and solar by 2030 (IEA 2019a). The LCOE is expected to reduce to approximately 50 EUR/MWh by 2035 (INR 4.36/kWh), once again a 40 percent reduction from the 80 EUR/MWh (INR 6.98/kWh) expected in 2023 (Aegir et al. 2021). Support is provided to the developers through Korea's Renewable Portfolio Standard (RPS), which replaced the FiT system that was effective until 2012. Under RPS, large power generators are required to fulfill renewable energy quotas by purchasing renewable energy certificates from independent power producers (IPPs). The IPP is required to sell the generated electricity at the system marginal price on the Korea Power Exchange.
LEVELS OF CUSTOMIZATION AND LOCALIZATION	• Leading companies have formed local partnerships to consolidate the industrial base of the country: steel, marine and offshore, and logistics. The existing marine and offshore industry can play a vital role in developing offshore wind energy in the country. Local shipyards in South Korea have already manufactured and supplied jacket platforms for offshore projects in Taiwan. Other local companies have already supplied offshore cables for the European market. Major industrial giants such as Hyundai and Samsung have the technical competence to manufacture vessels for offshore wind projects. This expertise can be used to accelerate the development of the offshore wind sector (Aegiret al. 2021; GWEC 2020).
PORTS	• More than 25 ports are distributed along the coast of South Korea. Many of the planned and active projects are located on the west coast. The ports of Incheon, Kunsan, and Mokpo are favorably located to service these projects. Major ports on the east coast include Ulsan and Busan. The port city of Ulsan has also entered a memorandum of understanding with domestic and foreign partners for the development of floating offshore wind farms (GWEC 2020).
TRANSMISSION	• The offshore wind collaboration plan by the government details plans to expedite the construction of and prioritize grid connections for large-scale offshore wind farms (Cho and Kwon 2020). We could not find information about the current status of the projects.

Table B6 | **South Korea (Cont.)**

TRANSPARENCY AND CERTAINTY	• Despite the slow start, offshore wind is gathering momentum in South Korea. The limited availability of land and the low irradiation levels for solar build a strong case for offshore wind as a renewable option. South Korea is also expected to be a leading floating offshore wind market by 2030 and is witnessing development in this area. The market shows promise, with over 23 offshore projects having a capacity of 7.3 GW under preliminary development (GWEC 2020). This has resulted in an influx of investments from both local and foreign players. However, the risk for a wind farm developer is still on the higher side when compared to European markets and needs to be addressed swiftly (Aegir et al. 2021).
SOCIOECONOMIC AND ENVIRONMENTAL CONSIDERATIONS	• The developer of the project is responsible for conducting EIA studies and presenting them for licensing approval. The Ministry of Trade, Industry and Energy, the Ministry of Oceans and Fisheries, and the Ministry of Environment have also jointly issued a "Plan for Offshore Wind Power Generation in Collaboration with Local Residents and the Fishing Industry" that aims to involve these entities in the planning process (Aegir et al. 2021).

Table B7 | **Taiwan**

POLICIES AND REGULATIONS	• The country has set ambitious targets for offshore wind as part of its green economy vision for the generation of 20 percent of its total electricity demand from renewables by 2025. Offshore targets stood at 5.7 GW for 2025 and another 10 GW by 2035. Other positive features include power sector reforms, liberalization of the electricity market, an open business environment, and the adoption of the FiT scheme for offshore wind energy procurement (GWEC 2020).
ENERGY PRICING	• Taiwan kick-started its offshore wind journey with two demonstration projects in 2012 that had a guaranteed power purchase agreement (PPA) coupled with an FiT mechanism whose rates gradually reduced over time. A competitive bidding process was introduced in 2018. In addition, the country has also seen a first of its kind renewable corporate power purchase agreement (CPPA) for offshore wind signed between Ørsted and Taiwan Semiconductor Manufacturing Company (TSMC) (Parnell 2020; GWEC 2020).
LEVELS OF CUSTOMIZATION AND LOCALIZATION	• Taiwan has attempted to promote large investments in the supply chain, resulting in the indigenous development of wind turbine components and subsystems. In 2020, partnerships were announced to facilitate domestic production of nacelles, turbine blades, and Taiwan's first offshore wind installation vessel (GWEC 2020).
PORTS	• At the current stage of its offshore wind development, Taiwan has identified Taichung port as the base for turbine assembly and local turbine manufacturing and Taipei port for the manufacturing, storage, and transport of underwater foundations. The Taiwan International Ports Corporation Ltd. (TIPC) has committed to emulating the achievements and status of ports such as Esbjerg (Netherlands) and Lowestoft (United Kingdom) (Greenport 2021).
TRANSMISSION	• The Taiwan Power Company has drawn up plans to provide grid connectivity for projects coming up at various times: 2021, 2024, and 2025. These involve either building new infrastructure or upgrading infrastructure (Liu 2019).
TRANSPARENCY AND CERTAINTY	• Taiwan has provided a clear roadmap in terms of the capacity additions for offshore wind that can be expected in the upcoming years. In addition, it has also earmarked zones where these projects are likely to come up, which drastically reduces the potential for conflict with, for example, military and fishing needs.
SOCIOECONOMIC AND ENVIRONMENTAL CONSIDERATIONS	• The Taiwanese Environment Protection Administration (EPA) is responsible for conducting reviews of offshore wind power and supervising EIA preparation. Key focus areas of the EIA are assessment of impacts on bird habitats and noise level limitations to protect the Chinese white dolphin (EPA 2021). • Attempts have been made to ensure that offshore wind project development goes hand in hand with community development. For instance, in Fangyuan County, offshore wind development has come into conflict with traditional oyster cultivation. The process that was followed went beyond the usual compensation mechanisms: jobs for the displaced, payments to the community, and community ownership of the wind farm. The Fangyuan project attempted to change the perception of offshore wind farm and community development, revive local culture, and integrate it into the development of offshore wind farms (OWFs). Similarly, the Ministry of Fisheries has issued a standard for offshore wind power plant compensation for fishery, which although not compulsory has been used by the OWF and fishing industries to arrive at negotiated settlements (Lin et al. 2019).

Table B8 | **China**

POLICIES AND REGULATIONS	• The Renewable Energy Law, released in 2006, was the foundation for offshore wind power planning and development, incentives, grid connection policies, and technical standards. In 2016, the National Energy Administration set a target of 10 GW of offshore wind by 2020 (Baiyu 2020).
ENERGY PRICING	• China commenced its first round of bidding in 2010. Two FiT rates were introduced for offshore wind projects and inter-tidal (or nearshore) projects. In 2018, a new regulation was introduced that approved price caps for competitive bidding of offshore projects approved in 2019 and 2020. At CNY 0.8/kWh (INR 9.13/kWh) and CNY 0.75/kWh (INR 8.56/kWh), respectively, these have seen a small decline from the FiT rate of CNY 0.85/kWh (INR 9.7/kWh) of 2014. The Chinese central government will also stop all subsidies to offshore wind projects from 2022 onward, but provincial governments are encouraged to continue them (GWEC 2020).
LEVELS OF CUSTOMIZATION AND LOCALIZATION	• In a short time, China has emerged as the world's largest market for new installations with more than 7 GW of offshore wind. China is also the third-largest market globally for offshore wind after the United Kingdom and Germany. This capacity addition, built on the existing onshore expertise, has led to the rapid development of offshore supply chains. There are multiple Chinese OEMs for large offshore turbines (>5 MW) (GWEC 2020).
PORTS	• Jiangsu had been identified as a key location for the construction of a port suitable for handling offshore wind projects (Carbon Trust 2014). Recent media reports indicate progress in the development of the port (New China TV 2021).
TRANSMISSION	• Developers are responsible for facilitating grid connectivity from the offshore project to the grid. However, local governments such as Yangjiang, Guangdong province, are thinking of splitting the connection into two parts and requiring the TSO to construct the segment from B to C (GWEC 2020).
TRANSPARENCY AND CERTAINTY	• The absence of information about future capacity addition has created an uncertain situation for investors and developers. In addition, the announcement regarding cancellation of subsidy from the central government has resulted in a scramble to complete projects. Official announcements need to be studied to understand the proposed pathway.
SOCIOECONOMIC AND ENVIRONMENTAL CONSIDERATIONS	• The State Oceanic Administration is the agency responsible for approving offshore locations for the proposed wind farms. The approval is granted after considering the environmental impacts of the project (Campbell et al. 2021). The EIA requirements for projects are summarized in Appendix C. • Currently, there is no specific national standard for fisher people's compensation. However, local governments (county level) do have detailed rules for compensation that differ from area to area. In general, fisher people's compensation depends on the local policy and negotiations with the local government.

Table B9 | **Japan**

POLICIES AND REGULATIONS	• Offshore wind has moved at a slow pace in Japan, mainly due to challenges related to EIA; regulatory uncertainties; and poor grid infrastructure in areas where offshore potential is available. The Port and Harbour Act of 2016 provided visibility for 20 years for offshore wind projects. Although this was an improvement over the previous visibility of 3–5 years, it was restricted to areas controlled by the local port authorities. Therefore, in 2018, the Bill on Promotion of Use of Territorial Waters for Offshore Renewable Energy Generation Facilities was introduced, which increased the exploitable area. The law also legalized offshore wind projects in the greater common sea area, which was previously reserved only for fishing. The bill also extended the contract duration to 30 years and added responsibilities under R&D, construction, and decommissioning for developers (IRENA 2021b). • In terms of capacity targets, there is no official declaration, but proposals from the Japan Wind Power Association (JWPA) indicate a desire to aim for 10 GW by 2030, 30–45 GW by 2040, and 90 GW by 2050 (JWPA 2020).
ENERGY PRICING	• In 2014, Japan introduced a 20-year FiT of 36 yen/kWh (INR 24.09/kWh) for offshore wind projects. In March 2020, an amendment was introduced that assigned the above rate to floating offshore wind projects; fixed foundation offshore wind projects have been moved to a competitive auction system (GWEC 2020).
LEVELS OF CUSTOMIZATION AND LOCALIZATION	• The Ministry of Land Infrastructure Transport and Tourism (MLIT), Government of Japan, has in its vision for the offshore power industry stated that although the offshore wind sector is poised to grow rapidly and Japan has companies that can potentially service the sector, the related industries are located in other countries. Hence, it has proposed increasing the Japanese content in projects to 60 percent by 2040. It proposes to do this by supporting capital investment through subsidies, tax incentives, and so on. It also proposes to help Japanese and foreign companies facilitate transfer of knowledge and technology and establish adequate infrastructure for businesses (MLIT 2020).
PORTS	• Four ports are under construction in Japan to make them suitable for handing offshore wind construction equipment and components: Noshiro, Akita, Kashima, and Kitakyushu. The MLIT has also stated that it will review how Japanese ports may need to function in the future considering the evolution of the offshore wind sector (MLIT 2020).
TRANSMISSION	• The importance of power evacuation planning is recognized by the Government of Japan. The first draft of the Power Grid Establishment Master Plan is expected in 2022 (MLIT 2020). As of now, there is no clarity on sharing of responsibilities for the construction of offshore plants.
TRANSPARENCY AND CERTAINTY	• Offshore wind auctions in Japan are planned to be zone specific. These are advantageous in the sense that the cost and time of an EIA can be greatly reduced and grid access made more certain if the zone is pre-identified and vetted by the government. • The auctions are expected to be held in at least five different Promotion Areas, selected by national authorities based on inputs provided by local governments. Local councils and relevant stakeholders will analyze the requirements for project bidding in each specific zone (IRENA 2021b). • However, defined targets are not available. These would be essential to bring in certainty for bidders.
SOCIOECONOMIC AND ENVIRONMENTAL CONSIDERATIONS	• Delayed environmental clearances were responsible for Japan's offshore capacity staying at low levels. The Japanese government has introduced a process that allows developers to commence EIAs and surveys and then bring them to the public hearing process. In addition, although the Offshore Wind Bill of 2018 does not mention this procedure explicitly, the fact that the government is creating identified exploitable areas seems to indicate that EIAs too would be included (Munir and Polito 2020). • Wind auctions in Japan are expected to include criteria beyond price. One example is how well the business plan aligns with local requirements, such as avoiding competition with fisheries (IRENA 2021b).

Table B10 | **Vietnam**

POLICIES AND REGULATIONS	• The Vietnamese renewables market is attracting global attention as it has plans to accelerate the energy transition by targeting 10 percent renewables by 2030. The country is undergoing industrialization and witnessing population growth, which is rapidly increasing its energy demand. Currently, Vietnam depends largely on thermal power plants to meet its power requirements, and the government has been proactive in implementing measures to minimize this reliance on thermal power while prioritizing renewable sources. The country has an offshore potential of 475 GW, and current plans target 6 GW of offshore by 2030. The first wind farm (16 MW) came online in 2013, and currently three projects with a combined capacity of 230 MW are under development. Approvals have also been received for commencing work on the 3.4 GW Thang Long project, which would be one of world's largest OWFs once it is commissioned. These projects are based on Power Development Plan 7 (PDP 7) of Vietnam, which emphasizes RE and liberalization of the energy sector (GWEC 2020).
ENERGY PRICING	• Currently, the offshore power purchase mechanism operates through FiTs. A draft of PDP 8 was released in 2020 and outlines an extension to the FiT framework with higher-capacity targets. There is also a proposal to extend the FiT deadline from November 2021 to the end of 2023. The draft policy also highlights the government's plans to transition to an auction for wind procurement by 2024. Direct PPAs and the development of a competitive power market are also under consideration. Challenges include the need for a transparent regulatory environment and the large capital required to execute offshore projects (GWEC 2020).
LEVELS OF CUSTOMIZATION AND LOCALIZATION	• We did not find Government of Vietnam sources mandating levels of local content. However, the World Bank, in its Roadmap for Offshore Wind for Vietnam, has estimated that by 2035, Vietnam's OWFs will have 60 percent of local content. These will be seen in the following areas: blades, towers, foundations and subsea cables, and large-scale construction and operations services (World Bank 2021). Stakeholder consultations have also confirmed the absence of a mandate at present and the overwhelming views that LCRs should grow gradually.
PORTS	• Fifteen ports located across Vietnam can be considered for supporting offshore development. Initial studies have confirmed the suitability of six of these ports for supporting offshore activities, with minor modifications: Hyundai–Vinashin Shipyard, Vietsovpetro Port, Tan Cang–Cat Lai Terminal, Tien Sa Port, PTSC Port (Vung Tau), and Tan Cang–Cai Mep Terminal. The ports located around Ho Chi Minh and Vung Tau have the potential to form clusters that can support offshore development. Out of the remaining nine ports, seven can support offshore activities through moderate modifications: Thi Vai General Port, SITV, Cam Ranh Port, PTSC Phu My Port, PTSC Dinh Vu, VICT, and Hiep Phuoc Port. The ports of Nghe Tinh and Duong Dong would require major modifications (World Bank 2021).
TRANSMISSION	• According to the extant procedures, the project developer needs to agree on a connection point with the power grid operator. The developer is then responsible for the entire interconnection (including any step-up transformers) (Campbell et al. 2021).
TRANSPARENCY AND CERTAINTY	• At the time of this writing, there is no confirmation that the FiT will be extended. Considering the COVID-19 situation, investors, developers, and the Ministry of Industry and Trade (MOIT) have sought an extension (Vietnam Electricity 2020).
SOCIOECONOMIC AND ENVIRONMENTAL CONSIDERATIONS	• Depending on the nature of the project, the developer is expected to obtain approval for the developed EIA from the Ministry of Natural Resources and Environment if the project needs investment approval from the National Assembly, National Government of the Prime Minister's office. For other projects, approval from the relevant provincial People's Committee is sufficient (Campbell 2021). • However, a recent conference elicited feedback from participants that the regulations covering assessment of impacts on environment and socioeconomic conditions do not provide complete guidance (Talk Vietnam 2021). • The installation and cables can disrupt commercial fishing practice. Policymakers and stakeholders are considering regulations and schemes to avoid conflicts.

APPENDIX C: ENVIRONMENT IMPACT ASSESSMENT REQUIREMENTS FOR OFFSHORE WIND PROJECTS IN CHINA

CONTENT OF MARINE EIA		OFFSHORE WIND POWER PROJECTS			
		Construction of wind turbines	Construction of submarine cables	Construction of step-up substations	Reclamation
Water Quality		●	●	○	●
Marine Sediment		●	●	○	●
Ecology	Biological Ecology	●	●	○	●
	Avian Ecology	●	—	○	○
	Landscape	○	—	○	—
Hydrologic Dynamic Environment		●	○	○	●
Landform and Scouring and Silting Environment		●	○	○	●
Noise (Under water and Above)		●	—	○	○
Electromagnetic Environment		○	○	●	—
Environmental Risks		●	●	●	●

When the step-up substation project is in the sea area, it is mandatory to assess the water quality environment, sediment environment, biological ecology, hydrologic dynamic environment, marine landform, and scouring and silting environment.

Notes: ● = mandatory, ○ = optional, — = no information available, EIA = Environmental Impact Assessment.

Sources: Information courtesy the WRI China Energy team.

APPENDIX D: POTENTIAL SOURCES OF FINANCE

The following are potential sources of finance to support an emerging offshore wind sector in India.

PUBLIC CAPITAL	• Tax breaks and export credits from the Union Government, state governments, and foreign governments. • Development Finance Institute (DFI): A new Indian DFI, the National Bank for Financing Infrastructure and Development (NaBFID) has been set up to support the development of long-term infrastructure financing in India (Reserve Bank of India 2022). Countries such as the United States, China, and Japan, and the EU have strategically deployed their DFIs to enhance infrastructure creation. India's DFI could provide the offshore sector with a significant amount of affordable debt once it becomes operational. • Indian Renewable Energy Development Agency (IREDA): This was set up as a Government of India non-banking financial institution under the control of MNRE for promoting, developing, and extending financial assistance for renewable energy (RE) projects. Since its inception in 1987, IREDA has been an active lender in the wind sector. As of January 2022, the government has approved an additional INR 15 billion equity infusion into IREDA that will allow it to lend an additional INR 120 billion to RE projects. Offshore wind projects can be prioritized and incentivized by IREDA to boost uptake of a new green technology.
IMPACT AND PHILANTHROPIC CAPITAL	• Multilateral development banks (MDBs): MDBs are significant sources of climate finance for developing countries; they provided $46 billion in climate finance in 2019. In September 2019, MDBs committed to increase their climate finance to $65 billion by 2025, up 50 percent from 2018 levels. Their mandates, instruments, and financial structures make them the most effective international means of helping developing countries increase access to finance. • Global Environment Facility (GEF): GEF provides climate financing through grants and co-financing. Its financial contributions are replenished every four years by donor countries such as the United States, United Kingdom, Germany, France, and Australia. It has funded 78 projects worth $580 million in grants and $5 billion through co-financing in India. • Green Climate Fund (GCF): GCF has set up the Private Sector Facility (PSF), a dedicated division designed to fund and mobilize private sector actors, including institutional investors, project sponsors, and financial institutions. The PSF deploys concessional instruments, including low-interest and long-term project loans, lines of credit to banks and other financial institutions, equity investments, and risk mitigators, such as guarantees, first-loss protection, and grant-based capacity-building programs.
PRIVATE COMMERCIAL CAPITAL	• Sovereign and pension funds • Large infrastructure investors such as the National Investment and Infrastructure Fund (NIIF) or Green Growth Equity Fund (GGEF) • Strategic capital from operating companies
DEBT CAPITAL	• Global green funds • Local banks

APPENDIX E:
MODEL FOR ROUND-THE-CLOCK POWER

We present the results of estimating the economic feasibility of a 1 GW round-the-clock (RTC) hybrid renewable facility consisting of 500 MW solar, 300 MW onshore wind, and 200 MW offshore wind. An RTC power facility of 1 GW is selected as it allows the plant to generate substantial energy and achieve economies of scale for the different renewable energy (RE) sources. The optimal RE mix is skewed toward sources that require a lower capex investment at today's prices and that broadly equalize the amount of power that the three sources generate on average. The levelized cost of electricity (LCOE) values are computed by considering the tariffs from the recent Solar Energy Corporation of India (SECI) RTC bid (for solar and onshore wind) and adding a premium for including offshore wind, based on discussions with industry experts. The RTC LCOE also builds in a reasonable enterprise value (EV)/earnings before interest, taxes, depreciation, and amortization (EBITDA) number, which suggests that we are not looking at investments that significantly exceed the required yield that is being generated by the EBITDA.

Table E1 | **Building an Economic Model for Bundling Renewable for Round-the-Clock Power**

	FORMULA	SOLAR	ONSHORE	OFFSHORE	STORAGE	TOTAL
Capacity (MW)	A	500	300	200		1,000
Proportion (%)		50	30	20		
Capex (INR mn/MW)	B	45	50	140		
Capex (INR bn)	C = (A×B)/1000	22.5	15	28	25	90.5
PLF (%)	D	20	35	40		
Generation (MW)	E = A×D	100	105	80		285
Generation (bn kWh)	F = (E×24×365)/10^6	0.9	0.9	0.7		2.5
RTC LCOE (INR/kWh)	G	3.5	3.5	3.5		
Revenue (INR bn)	H = F×G	3.1	3.2	2.5		8.7
EBITDA margin (%)	I	90	90	90		90
EBITDA (INR bn)	**J = H×I**	**2.8**	**2.9**	**2.2**		**7.9**
EV/EBITDA	K = C/J	8.2	5.2	12.7		11.5

Notes: mn=million, bn=billion, Assumed 5 hours of storage on total generation capacity and INR 7 billion per 400 MWh based on tariff analysis of the policy on battery storage.

Sources: Industry data, assumptions, NIIF calculations.

NOTE ON CURRENCY CONVERSION[6]

1. 1 Euro = INR 87.27
2. 1 US$ (United States Dollar) = INR 73.81
3. 1 Japanese Yen = INR 0.67
4. 1 CNY (Chinese Yuan/Renminbi) = INR 11.39

ENDNOTES

1. PX is a term used in resource estimation of RE projects to indicate the annual level of generation, where the output is expected to exceed X percent over a year.
2. We understand that revised LCOE numbers are likely to be announced by the COEFOWRE after acceptance by the Government of India.
3. Viability gap funding is the provision of financial support by the government to crucial sectors in order to accelerate economic development by funding infrastructure projects when the project cost is too high for the private sector.
4. Grid connectivity in subsequent discussions will refer to the schematic in Figure 3.
5. The pricing structure of electricity supplied to consumers.
6. Source: https://www.xe.com/.

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