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OFFSHORE WIND ENERGY AS AN EMERGENT OCEAN INFRASTRUCTURE IN INDIA: MAPPING OF THE SOCIAL AND ENVIRONMENTAL IMPACTS

Gopal K. Sarangi

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Gopal K. Sarangi is an assistant professor at the TERI School of Advanced Studies in New Delhi, India.

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Please contact the authors for information about this paper.

Email: gopal.sarangi@terisas.ac.in

Asian Development Bank Institute
Kasumigaseki Building, 8th Floor
3-2-5 Kasumigaseki, Chiyoda-ku
Tokyo 100-6008, Japan

Tel: +81-3-3593-5500
Fax: +81-3-3593-5571
URL: www.adbi.org
E-mail: info@adbi.org

Abstract

Offshore wind energy holds promising potential as an alternative source of energy for a country like India, which continues to be land deprived and faces increasing difficulty in acquiring land for energy. While some scholarly efforts have focused on the Indian context, there is a dearth of studies on the associated environmental and social challenges of such infrastructure deployment. The paper conducts a detailed assessment of the policy and institutional mechanisms governing the offshore wind energy in the country and identifies the possible environmental and social impacts of such projects on the marine environment and livelihood of fishing communities in India. It employs qualitative research approaches and various types of secondary information and data. The policy and institutional framework assessment reveals that, despite the creation of the required mechanism, significant gaps exist in the knowledge of such projects' possible impacts through these policies and regulations. Impact mapping shows that offshore wind projects could adversely affect the marine eco-system and marine biodiversity to varying degrees over their entire life. The impacts occurring during the construction and operation phases of the project cycle will be significant. Policy suggestions show that preparatory measures are necessary before the implementation of such projects.

Keywords: offshore wind energy, environment, livelihood, India

JEL Classification: E2, O13, O18, Q42

Contents

1. INTRODUCTION

In the basket of renewables, offshore wind energy is emerging as a promising energy source worldwide, having far-reaching potential to meet the burgeoning energy demand. The International Energy Agency (IEA) (2018) has even recognized that "off-shore wind energy is a rising force." Globally, offshore wind energy is gaining traction as an alternative source of energy, and the technology is fast achieving maturity and increasing its market penetration. Countries are also prioritizing offshore wind as a source of energy to mitigate climate-related challenges.

Given that this source of energy is carbon neutral and can meet the growing appetite for energy, coastal countries across the globe are considering it as a potential source. Though offshore wind assets constitute 5% of the total deployed wind assets globally, with cumulative global installations of 30 GW, projections have indicated that it will grow rapidly in the future to meet the renewable target of 2030. It has become an important part of the green and blue recovery of many countries impacted by COVID-19 pandemic. Some countries, like the UK, are even renewing their focus on offshore wind energy as a mechanism to realize the ambitious 2050 target of net zero emissions. The projections of the International Renewable Energy Agency (IRENA) (2020) have revealed that the global offshore wind energy capacity will touch 228 GW by 2030 and could further leapfrog to 1000 GW by 2050. While European countries are taking the lead in deploying such energy assets, several countries in the Asia and the Pacific region are showing fresh interest in this form of energy. IRENA (2020b) projects that Asia will take the lead in future offshore wind energy capacity addition. The European success story largely draws its strength from regional cooperation for interconnection along with well-designed marine spatial planning, which appear to be critical for the successful deployment of offshore wind energy. Importantly, one of the major drivers of offshore wind energy deployment is the dramatic reduction in the cost of electricity from this source of energy. IRENA's (2020b) estimations revealed that the levelized cost of electricity (LCOE) plummeted from USD 0.16 per kilowatt-hour (kWh) in 2010 to USD 0.13/kWh in 2018 and is likely to fall further in the future.

India is making long strides in driving its varied sources of renewables and has taken strategic policy actions in that direction. Both global commitments and domestic compulsion have redefined and reconfigured the country's focus on renewable energy development. The target to deploy 500 GW of energy from non-fossil fuel by 2022 is a clear manifestation of such policy thrusts. To achieve the target and to meet the country's surging energy demand, it is also imperative to diversify its energy portfolio to include all possible renewable energy sources. Offshore wind energy, among other things, offers an opportunity to diversify India's renewable sources and exploit this new form of energy. The importance of achieving energy security and provisioning quality and reliable energy holds primacy as the country performs poorly in several key energy indicators. For instance, while India's per capita electricity consumption is close to 1100 kWh, that of the People's Republic of China (the PRC) is four times higher.

India, being a resource-rich country in terms of having a coastline 7600 km long, possesses huge potential for offshore wind energy generation. Offshore wind energy is promising as an alternative source of energy for a country like India, which continues to be land deprived and is increasingly facing difficulties in acquiring land for energy projects. In addition, the momentum behind the blue economy, with its emphasis on utilizing the "ocean as a resource," has reiterated the need to exploit this vital source of energy. Some estimates have revealed that the blue economy's share at present is 4% of the country's GDP, and this figure is likely to rise in the future. Besides, policy makers are considering offshore wind energy as a "strategic source of energy" to achieve energy security in the country. They are prioritizing offshore wind energy as it has higher capacity factors than its counterpart onshore wind energy (Wei, Zou, and Lin 2021). Studies have also asserted that offshore wind could offer a more predictable source of energy than its counterparts, solar PV and onshore wind (IRENA 2020b; Kumar et al. 2020). It can better serve the load centers near the coastline and can be a major source of energy for them in the future. Though potential estimates have varied significantly across studies, the offshore wind energy potential in the country reportedly lies somewhere between 200 GW and 500 GW (Mani and Dhingra 2013a). Considering the potential, the available technology, and the cost, the country has set medium-term and long-term targets of deploying 5 GW of offshore wind energy by 2022 and 30 GW of offshore wind energy by 2030. In fact, the country has undertaken the initial efforts in 2018 to deploy 1 GW in an offshore wind project on the Gujarat coast. However, the project became mired in controversy and has not taken off so far due to a high CAPEX and a lack of government support (Bhatti 2021). In fact, there have been shifts in the industry's interest from Gujarat to Tamil Nadu due to the high wind resource potential and favorable geotechnical conditions in the state of Tamil Nadu.

Kumar et al. (2020) asserted that offshore wind energy would be a critical addition to the country's current emphasis on renewables. To drive the offshore wind energy development in the country, the Ministry of New and Renewable Energy (MNRE) issued a dedicated policy called the "National Offshore Wind Energy Policy" in 2015. The most recent development was the MNRE's declaration of the "Draft Offshore Wind Energy Lease Rules, 2019," which has spelt out mechanisms to lease out blocks for offshore wind energy projects.

Though a good number of scholarly efforts in the past have focused on analyzing various aspects of offshore wind energy development in the country, such as the potential and feasibility of deployment, the need for policy drivers and policy instruments, technological configurations, and the geophysical aspects of such potential, there has been a dearth of scholarly studies understanding and analyzing the possible environmental and social conundrums of such large-scale infrastructure deployment. For instance, Nagababu, Kachhwaha, and Savsani (2017a) and Nagababu, Kachhwaha, Naidu, and Savsani (2017b) attempted to assess the offshore wind energy potential and feasibility of deploying such technologies in the country by employing GIS and remote sensing tools. Similarly, Mani and Dhingra's (2013a, 2013b, 2013c) studies largely focused on the policy aspects of offshore wind energy development in India and evaluated the need for a robust set of policies and policy instruments for the large-scale deployment of offshore wind energy in the country. On other hand, some studies (Kota, Bayne, and Nimmagada 2015) have attempted to compare the offshore wind energy development in India with that in the UK and the US. These studies showed that there has been poor understanding of the possible environmental and social impacts of such infrastructure deployment. This is partly because of a lack of physical presence and implementation of such projects at present; however, such an understanding is of the utmost important at this juncture as the country is gearing up for the deployment of such assets in the near future (Aggarwal 2019). Several studies in other country contexts have pointed to the environmental and social challenges involved in offshore energy deployment (Bergström, Sundqvist, and Bergström 2013; Bailey, Brookes, and Thompson 2014; World Wide Fund for Nature (WWF) 2014).

In this context, the present study aimed to undertake the following tasks:

- To analyze critically and assess the policy and institutional framework governing offshore wind energy development in the country from the perspective of its environmental and social impacts;
- To carry out a detailed mapping of the possible environmental and social impacts of such projects on marine ecology and the livelihoods of fishing communities.

The study has employed a qualitative research approach by using various types of secondary information and data. It carried out a detailed assessment of the existing laws and policies to understand and analyze critically the legal and institutional framework governing such projects. It gathered various types of secondary data and information to map the possible impacts of these projects. The gathered information aligned with that of similar studies in other country contexts that have assessed such impacts. In addition, a select set of expert consultations were carried out to understand the contextual impacts of such infrastructure projects in the Indian policy setting. The findings of the study will help policy makers in their decision to deploy such projects and in taking the necessary policy actions at all layers of governance to minimize their environmental and social threats.

The structure of the paper is as follows. The next section presents the importance of offshore wind energy as an emergent infrastructure. The third section describes the policy and institutional framework that governs offshore wind energy development in the country. The fourth section identifies the possible impacts of offshore wind energy projects, drawing from international experiences. The fifth section maps the possible ecological and social impacts of such projects in India. The sixth section offers a future roadmap that minimizes the adverse environmental and social impacts of these projects. The final section concludes the paper.

2. OFFSHORE WIND ENERGY AS AN EMERGENT OCEAN INFRASTRUCTURE IN INDIA

India has 7600 km of coastline, offering huge offshore wind energy potential. It also has 2.3 million square kilometers of Exclusive Economic Zones (EEZs), which offer an enormous offshore area for the deployment of ocean infrastructure. The country has nine maritime states, of which Gujarat has the longest coastline, followed by Tamil Nadu. The creation of offshore energy infrastructure in India is not new; the offshore oil and gas industry has been thriving for quite some time. India's Oil and Natural Gas Corporation (ONGC) has been operating offshore oil and gas fields in Mumbai, known as "Bombay High," since 1976. Similarly, there have been offshore energy assets deployed on the eastern coast of the country, in the Krishna–Godavari–Mahanadi basin. Studies have reported that the deep water basins of Mahanadi also hold good potential for hydrocarbons. The most recent development in this space was the subsea development project of Reliance and British Petroleum (BP) in the Krishna–Godavari basin. They installed ultra-deep infrastructures for the extraction of gas. Three recently developed deep water gas projects have the potential to fulfill 15% of India's gas demand by 2023. The most recent development in this space is the Government of India's proposed "Deep Ocean Mission," which emphasizes, among others, exploring minerals and energy, and the Ministry of Earth Sciences of the Government of India has lauded it as a "futuristic and game changing" mission. The Union Budget of the Government of India 2021–22 placed special emphasis on the Deep Ocean Mission, with a budgetary allocation of 4077 crore INR over a 5-year period. Although offshore wind energy received an explicit mention in the Mission, its larger goal is to accelerate the blue economy, which can contribute to India's development and help in meeting India's future energy requirements.

Offshore wind energy is new to the country, and such technologies are evolving fast globally. Offshore wind energy technologies have been developing globally over the past three decades. They have received high prioritization due to their strength and steadiness and their greater efficiency and predictability (Kumar et al. 2020; Wei 2021). The cost of generating electricity using these energy sources remains high; however, the expectation is that it will fall in the near future with the large-scale deployment of such systems and technological advancements (IRENA 2020b).

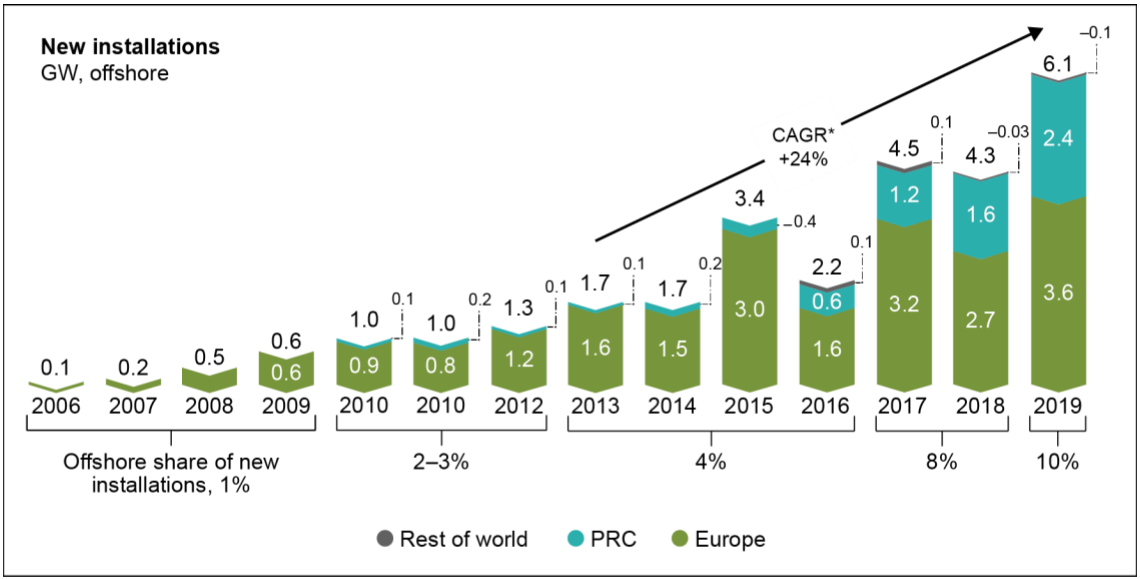
There have been several efforts globally to develop offshore wind assets of varying forms and sizes. While Europe leads in terms of the deployment of offshore wind installations, the PRC is fast ramping up its new capacity and dominates in terms of new capacity additions, energy generation, and technological advancements, and other nations in the Asia and Pacific region, like Taipei,China; Viet Nam; Japan; and the Republic of Korea, are increasingly paying attention to offshore wind energy as an alternative and efficient source of energy. Though offshore wind assets constitute 5% of the total deployed wind assets globally, with cumulative global installations close to 30 GW, projections have indicated that they need to grow rapidly in the future to meet the renewable target of 2030. IRENA's projections revealed that the global offshore wind energy capacity will touch 228 GW by 2030, further escalating to 1000 GW in 2050 (IRENA 2020a). The year 2019 showed a historical record of 6.1 GW deployment of offshore wind energy assets globally (Figure 1). The projections of the Global Wind Energy Council (GWEC) (2020) also revealed that India has high potential for offshore wind energy and will be producing from this source from 2027 onwards. Table 1 presents the cumulative offshore wind installations so far globally, and Figure 1 shows the compound annual growth rate of offshore wind energy across the globe.

Table 1: Cumulative Offshore Wind Installation in Major Offshore Wind-Deploying Countries

Country	**Installed Capacity** (MW)
UK	9,603
Germany	7,566
PRC	6,984
Denmark	1,746
Belgium	1,455
The Netherlands	1,164
Others	582

Source: GWEC (2020).

Figure 1: Compound Annual Growth Rate of Offshore Wind Energy



Source: GWEC (2020).

In the Indian context, though some crucial developments have taken place in offshore wind energy, the implementations are still in the nascent stage. Offshore wind energy is emerging as a crucial source of energy and a preferable alternative to onshore wind energy due to the inherent land acquisition problems combined with the increasing difficulty in obtaining windy sites. Given that India has a successful history of onshore wind energy and ranks as the fourth-largest wind energy producer globally, it is likely that it could capitalize on some of the experiences of and learning from onshore wind deployment for its offshore wind energy deployment. It is an opportune time for the country to accelerate its offshore wind development given the favorable economic and climate-related commitments and compulsion.

Multiple agencies have estimated the offshore wind energy potential in the country. For instance, according to the estimates of the Lawrence Berkeley Laboratory, India has close to 214 GW of offshore wind energy potential (Phadke et al. 2012). Mani and Dhingra (2013a), in one of their studies, estimated that the potential of offshore wind energy in India lies between 200 GW and 500 GW. However, most potential sites lie along the coasts of Gujarat and Tamil Nadu. Some of the Government of India's preliminary estimates have revealed that Gujarat alone has the potential to generate around 106 GW of offshore wind energy, whereas Tamil Nadu has potential close to 60 GW (Aggarwal 2019), two high potential states in India, and the rest of the potential lies in other coastal states.

FOWIND (2017) carried out detailed baseline mapping and supply chain assessment and investigated the feasibility of grid integration for these two Indian states, that is, Gujarat and Tamil Nadu. The report identified five crucial factors for offshore wind development in the country: drawing a long-term roadmap, developing a transparent consent and permission system, strengthening the regional and national grid, developing a well-structured financial support system, and developing the necessary skill sets and competencies. According to the FOWIND (2017) study, the roadmap should involve identifying the policy drivers, setting the targets, and laying out a clear implementation plan. Given that the technology is nascent and quite complex, clear procedures are necessary in which consent and permission should be consistent, which would boost private investors' spirit to venture into this risky sector. The third important aspect is grid integration. The problem of poor grid integration will have technical as well as financial implications for the sector's development. This will become more pronounced due to the lack of a policy for offshore energy transmission. The fourth most important factor is the creation of an eco-system for the provisioning of the much-needed financing for the sector given that these technologies are nascent and the cost of generating electricity is relatively high compared with the cost of other forms of energy. The government should extend the necessary financial support through the provision of smart subsidies along with easy access to credit for project developers. The final and most important factor is the development of the necessary skill set and competencies. A diverse set of skills is necessary during the life cycle of an offshore project. The most necessary skills are specialized and hence require building over time. Therefore, there is a need to develop an indigenous skill set through framework agreements with other countries for training and capacity building, through knowledge transfer, and through joint partnerships during projects' execution, implementation, and decommissioning (FOWIND 2017).

While there have been some efforts to install the first 1 GW of offshore wind energy in the country in the Gulf of Khambhat, on the coast of Gujarat, the progress is slow and tardy. Toward that end, the efforts have been undertaken to conduct the required geophysical study for an area of 365 square kilometers as well as geotechnical and met-ocean studies and the seeking of stage I clearance following the guidelines of the "National Offshore Wind Energy Policy, 2015." The Ministry of New and Renewable Energy (MNRE) has also highlighted that the National Institute of Oceanography, Goa, has the responsibility for carrying out the Environmental Impact Assessment (EIA) of the proposed project site. The next stage in the process is to select a developer through a competitive bidding procedure and then seek the stage II clearance for the project. Expecting the tariff to be high for this project, the MNRE has proposed to provide central financial assistance in the form of viability gap funding (VGF). However, the project has suffered considerable delays and has been unable to meet the target schedules. There are further proposals to deploy LiDAR off the coasts of Gujarat and Tamil Nadu to carry out wind resource assessment along with geophysical, geotechnical, and oceanographic studies (Randall-Smith 2020).

3. POLICY AND INSTITUTIONAL FRAMEWORK GOVERNING THE OFFSHORE WIND ENERGY DEVELOPMENT IN INDIA

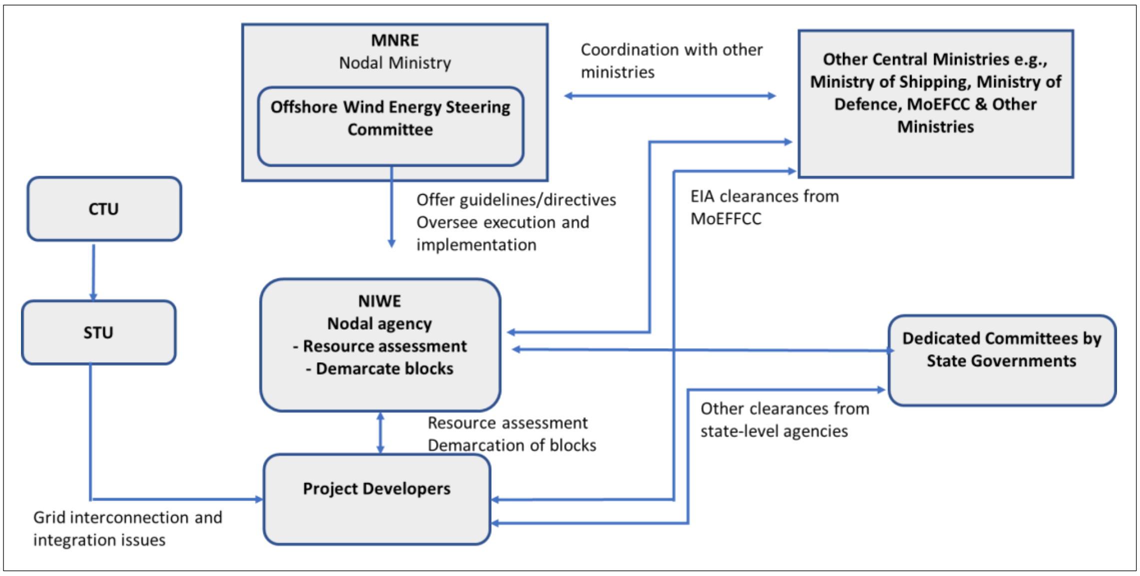
It is necessary to highlight the larger policy and institutional framework governing the ocean infrastructure in general and offshore wind energy in particular. Both the union government and the provincial governments in India largely govern the marine resource management. This has led to often overlapping and conflicting jurisdiction of existing laws, regulations, guidelines, and notifications among the different layers of institutions, resulting in ambiguities in ocean governance in India. In addition, climate change considerations have compounded the problems of marine resource governance and management in India (Jayaram 2016). However, the emphasis in this section is on assessing the major laws, regulations, and notifications that directly and indirectly affect the offshore wind energy development in the country.

Two sets of recently declared policies and guidelines, namely the "National Offshore Wind Energy Policy, 2015" and the "Draft Offshore Wind Energy Lease Rules, 2019," govern the most important and most direct policy environment of offshore wind energy in India. These two policy documents set the tone and lay down the governance setting for the offshore wind energy policy making in the country. This section presents a detailed and critical mapping and evaluation.

3.1 National Offshore Wind Energy Policy, 2015

Considering the importance of offshore wind energy in India, the Government of India has produced the "National Offshore Wind Energy Policy" in 2015. The policy has set out the institutional mechanism for the offshore energy development in the country. The Ministry of New and Renewable Energy (MNRE) of the Government of India acts as the nodal ministry. As a nodal agency, the MNRE is responsible for carrying out the overall monitoring of projects, coordinating with other ministries, offering guidelines/directives, providing support for the nodal agency, the National Institute of Wind Energy (NIWE), promoting international cooperation, and conducting coordination in matters relating to tariff decisions and other such regulatory matters. The National Institute of Wind Energy (NIWE) acts as a nodal agency for conducting the resource assessment and demarcating blocks for facilitating the development of offshore wind energy in the country. In addition to the nodal ministry and the nodal agency, the policy refers to the formation of an 'Offshore Wind Energy Steering Committee' within the Ministry of New and Renewable Energy (MNRE), with the Secretary as its chairman, which would not only provide policy guidelines from time to time but would also oversee the execution and effective implementation of offshore wind project activities on a regular basis. In addition, the Ministry of Shipping, Central Transmission Utilities (CTU), and State Transmission Utilities (STU) will be part of the offshore wind energy development in the country. Besides, given that these technologies are new and complex, the policy requires clearance from a host of ministries, such as the Ministry of Defence and the Ministry of Environment, Forest, and Climate Change. Figure 2 presents a schematic of the institutional mapping.

Figure 2: Schematic of the Institutional Mechanisms Governing Offshore Wind Energy in India



Source: Author's construct.

The detailed mapping of the policies reveals that they offer a broad policy framework for the development of offshore wind energy in the country. It highlights that offshore wind energy is at the nascent stage of development and has yet to gain a comparable position with other competing sources of renewables. Since onshore wind energy is one of the country's successful initiatives, it is likely that offshore wind energy will draw from the rich and varied experiences that it has gained from onshore wind energy and embed the best practices of onshore wind energy into the framing and implementation of offshore wind energy projects. The policy document also highlighted that India has reasonable potential for offshore wind energy development and that, in India, two main maritime zones are potential areas for offshore wind energy development: 1) within India's territorial waters, which cover 12 nautical miles from the coastline toward the sea; and 2) Exclusive Economic Zones (EEZs) beyond 12 nautical mile areas into the sea up to 200 nautical miles. The targets for offshore wind energy are to produce 5 GW by 2022 and 30 GW by 2030. The policy objectives clearly emphasize the need for such policies both from the energy security point of view and from the carbon reduction point of view. They also prioritize the need for public–private partnerships for offshore wind energy development, promoting such wind farms in the country's Exclusive Economic Zones (EEZs).

The policy recognizes a host of challenges, such as resource characterization, subsea cabling, turbine foundation, the installation of turbines, including logistics, grid interconnection, and operation issues, the construction of transmission infrastructure, integration with the national grid infrastructure, and associated coastal security issues, for the development of offshore wind energy in the country. The policy acknowledges the important aspect of the impact of such projects on fishing and the livelihood of local fishing communities during the project planning stage and prescribes that projects should make all efforts to avoid developing project sites in fishing grounds. If there is a need to relocate the fishing grounds, fishing communities should be given adequate compensation in accordance with the policies of the central/state governments. In addition, the policy recognizes the need to carry out Environmental Impact Assessment (EIA) to assess the impact on aquatic life and fishing; this is unique in the forms of renewable energy development in the country. As part of the EIA, the policy guidelines suggest that the developer should provide the details of decommissioning and site restoration before the offshore construction begins. In this regard, it should gain the necessary clearance from the Ministry of Environment, Forests, and Climate Change (MoEFCC) and other ministries. It also gives state governments the responsibility for forming dedicated committees for the development and promotion of offshore wind projects in their respective states.

While the policy speaks volumes about various aspects of offshore wind energy development in the country, the proof of the pudding lies in the eating. The effectiveness of the policy is in its implementation. Though the proposal to deploy 1 GW of commercial offshore wind energy in the Gulf of Khambhat represents some efforts in that direction, the progress has been slow at best. The policy has certain lacunae, such as the lack of a permission and consenting regime for wind energy. Given the context-specific nature of the impacts of such policies, the policy does not explicitly mention the development of the needed institutional mechanism at the decentralized level. In addition, the policy document does not refer to other environmental laws, regulations, and guidelines that apply to such projects. While it discusses environmental and social impacts, carrying out such assessments requires a contextual understanding and the devising of strategies at the local scale.

3.2 Draft Offshore Wind Energy Lease Rules, 2019

The second most important policy guideline is the “Draft Offshore Wind Energy Lease Rules, 2019,” which has a specific focus on lease rules. Here, the study extracts and analyzes relevant environmental and social provisions to highlight the way in which the rules deal with these matters. They assign primacy to the “decommissioning” of the project, in which the uprooting and demolition of foundation structures and the removal of debris will follow the relevant marine environmental norms. It also states that the lessee does not have the right to block or bar routine activities, including activities related to fishing. Another important clause concerns the cancellation of the lease agreement if the project causes environmental damage to flora and fauna lying under the sea and can pose threats to human life and property both while carrying out activities under water and while operating during the lease period. In addition, the rules state that the union government may take over the operation if the lessee misuses the operation of offshore wind zones/areas, including environmental protection. The central government can shut down the firm if it finds that it is causing damage to the environment or property and generating pollution.

3.3 Other Laws and Regulations Governing the Marine Environmental Systems

While the “National Offshore Wind Energy Policy, 2015” and the “Draft Offshore Wind Energy Lease Rules, 2019” refer to direct environmental and social considerations concerning offshore wind energy deployment in the country, there are other laws and regulations governing the marine environmental systems that have a bearing, albeit indirectly, on the offshore wind energy deployment in the country.

One such regulation is the “Coastal Regulation Zone Notification, 2019.” Under such notification, while the central government specifies the coastal regulation zone norms, the state government should declare its coastal zone management plans and set up a Coastal Zone Management Authority (CZMA). The framing of these notifications falls under the umbrella legislation of the Environmental Protection Act 1986 and hence their design is primarily intended to protect the marine ecosystem and marine environment. The government framed the first rule in 1991, further revising it in 2011 to allow some flexibility, and declared the latest one in 2018–19. According to the latest rule, the thrust is on the management and conservation of marine eco-systems, the promotion of coastal areas, eco-tourism, and livelihood options with specific reference to fishing communities and sustainable development at large. While different segments of zones exist, ecologically sensitive areas (CRZ I), such as mangroves, coral and coral reefs, sand dunes, biologically active mudflats, other parks, salt marshes, turtle nesting grounds, horseshoe crab habitats, sea grass beds, and nesting grounds of birds, require specific attention. It clearly identifies the coastal areas that require special focus and consideration, declaring as critical vulnerable coastal areas (CVCAs) the Sundarban region of West Bengal, the Gulf of Khambat and Gulf of Kutchh in Gujarat, Malvan, Achra-Ratnagiri in Maharashtra, Karwar and Coondapur in Karnataka, Vembanad in Kerala, the Gulf of Mannar in Tamil Nadu, Bhaitarkanika in Odisha,[1] and Coringa, East Godavari, and Krishna in Andhra Pradesh.

[1] In 2011, the Government of India approved the name change of the State of Orissa to Odisha. This document reflects this change. However, when reference is made to policies that predate the name change, the formal name Orissa is retained.

In addition, India, as a signatory to the "Convention on Biological Diversity" (CBD), has to follow the conservation norms that the CBD has specified. It identifies protected areas as key mechanisms to safeguard biodiversity (Legal Initiative for Forest and Environment 2014). Marine protected areas (MPAs), which come under the CBD, constitute an important component of marine biodiversity and marine eco-systems. Four key areas are legally declared protected areas, specifically national parks or wildlife sanctuaries, conservation reserves, and community reserves. Nearly 700 such locations had recognized as protected areas in India by 2014 (Sivakumar, Mathur, and Pande 2013). These MPAs provide a range of ecological services. Table 2 presents a mapping of the impacts and gaps drawing from the key policies and regulations governing offshore wind energy in the country.

Table 2: Mapping of the Impacts and Gaps from the Key Policies and Regulations Governing Offshore Wind Energy in the Country

Policy	Identified Impacts	Proposed Measures	Identified Gaps
National Offshore Wind Energy Policy, 2015	Impacts on fish catching and livelihood impacts on fishing communities	Not to develop project sites on fishing grounds; in the case of relocation of fishing grounds, to provide adequate compensation	Lack of a wind permission and consenting regime; lack of clarity on local-level institutional mechanisms; lack of clarity regarding integration with other marine laws, regulations, and guidelines
	Impacts on aquatic life and fishing	Need to carry out EIA; the developer should provide details of decommissioning and site restoration	
Draft Offshore Wind Energy Lease Rules, 2019	Impacts during the decommissioning of the projects	In accordance with the marine environmental norms	No clarity on the exact nature of impacts and stages of impacts; lack of clarity regarding integration with other marine laws, regulations, and guidelines; no assignment of a specific role to state governments or other decentralized bodies
	Impacts on fish catching	No right to block or bar routine activities, including activities related to fishing	
	Damage to flora and fauna	Cancellation of the lease agreement if the project causes environmental damage to flora and fauna lying under the sea	
	Damage to the environment and the generation of pollution	Shutting down of firms	

Source: Author's compilation and analysis.

4. POSSIBLE IMPACTS OF OFFSHORE WIND ENERGY PROJECTS

Oceans deliver a range of material, economic, and non-economic benefits. In fact, the importance of oceans and their ecological significance has become more pronounced in the face of the ongoing COVID-19 crisis.

While offshore wind energy projects generate a host of benefits compared with other forms of renewable energy, such as high efficiency, no land requirement, and negligible transmission costs, it is possible that these forms of energy interventions involve significant environmental and social costs (WWF 2014). Most importantly, studies have pointed out the inherent uncertainties of the environmental impacts of offshore wind energy projects. They have asserted that often environmental effects could sustain through the entire project life cycle. Studies assessing the environmental and social impacts of offshore wind energy projects have often posited that these projects generate both positive and negative environmental impacts. One of the most-cited positive impacts is the formation of artificial reefs through the turbine structures (Kumar et al. 2020). Researchers have asserted that these artificial reefs could enhance the species population and biomass types. Artificial habitat creation through reefs may increase the fish population, bird species, and marine mammals (Lindeboom et al. 2011).

However, some reports have denied such claims of increased diversity of ocean animals and fish populations following the deployment of offshore wind energy plants (Bergström et al. 2013). Negative impacts are also apparent in terms of the construction of offshore wind energy plants and consequent activities, such as transportation, deployment, and operational noise, and their impacts on marine life and marine eco-systems (Kumar et al. 2020). For instance, understanding the water depth and seabed characteristics is a crucial element of the deployment of such systems as this knowledge helps to identify the deployment sites. Similarly, the type of wind turbine generator (WTG) and its positioning are two very important components of projects, which may have significant environmental and ecological impacts. If not properly designed and contextualized, the generator may create possible environmental impacts, such as disturbing sea bird feeding areas, fish spawning areas, and protected species, along with negative visual impacts. For instance, the construction of wind plants within the sea impairs seabed habitats and generates negative consequences in the long run (Bailey, Brookes, and Thompson 2014). Offshore wind energy farms reportedly have negative impacts, decreasing the marine population, richness of species, biodiversity, functioning of marine species, their abundance, and their community structures and often affecting the behavior of marine lives. However, the cumulative environmental and ecological impacts are not clear and are often context based. Some studies have reported the visual impacts of offshore wind farms and pointed out that the nearer the installation of farms, the greater the visual impacts (Parsons, Firestone, Yan, and Toussaint 2020). The noise that these projects emit might also have negative environmental consequences for marine species and their movements. The generated noise is harmful for mammals (Thompson et al. 2013; Bailey, Brookes, and Thompson 2014; Kumar et al. 2020), loud sounds could also be detrimental to sea animals, causing hearing impairments and obstructing their communication, leading to their migration and relocation (Thompson et al. 2013; Bailey, Brookes, and Thompson 2014; Kumar et al. 2020).

Apart from the environmental impacts, these energy infrastructures generate a host of social impacts. Research has asserted that understanding the human dimension of such projects is vital for their successful implementation. Some studies have raised concerns about the impacts on the fishing industry (Ciara, Garcia, Ortega, and Richmond 2020), and others have identified the negative impacts on eco-tourism (Kumar et al. 2020). The local area and local people, terrestrial life and marine life, and the ocean eco-system would experience significant impacts.

5. MAPPING THE ECOLOGICAL AND SOCIAL IMPACTS OF OFFSHORE WIND ENERGY PROJECTS IN INDIA

While the full-scale impact of offshore wind projects in India will only be apparent after their implementation, drawing from the international experiences and expert interactions, this study mapped, identified, and contextualized a host of possible impacts to understand their magnitude and their varying dimensions. Given that these projects involve large degrees of uncertainty regarding their environmental and social impacts (IRENA 2020b; Kumar et al. 2020), it is imperative to carry out full-scale mapping for offshore wind projects. Studies have contended that the extent and magnitude of the ecological disturbances that these projects may generate are still unexplored, underestimated, and at best poorly mapped (Kumar et al. 2020). This mapping exercise becomes more pertinent as most of the renewable energy in India does not fall under the ambit of the EIA Notification of 2006, and the pollution regulatory authorities at the sub-national scale (i.e., State Pollution Control Boards) tag renewable energy projects such as solar and wind as "green" (Thapar 2017).

Recent developments have also pointed to the need to perform this mapping exercise. For instance, some preliminary observations have revealed the looming dangers of extracting hydrocarbons from oceans in India and the possible ecological hazards of such extraction for ocean flora and fauna (Singh 2020). Notably, the recent focus on the blue economy, in which the private sector plays a dominant role in the exploitation of ocean resources, has brought the debated issue of social licensing to operate to the forefront (Roy 2019; Voyer and Leeuwen 2019). Traditionally, people have considered the ocean as a common pool resource that has deep social, cultural, and spiritual connections with the people of India (Roy 2019) and that is a major source of livelihood for a large chunk of the Indian population (Singh 2020). For instance, in India, close to 15 million people draw their livelihood from fishing and fishing-related activities alone, and fishing contributes nearly 5% of the GDP and 10% of foreign exchanges for the country. In addition, a range of climate-related challenges, such as ocean acidification, extreme weather events, and sea-level rise, have exacerbated the problems affecting the aquatic lives of ocean inhabitants, their distribution and movement patterns, and their behavior. Poor ocean literacy is arguably also causing problems in marine conservation and ecological restoration.

5.1 Environmental Impacts of Offshore Wind Projects

The Indian Ocean system is rich in eco-systems, such as beaches, mangroves, coral reefs, estuaries, islands, tidal mudflats, lagoons, marshes, and vegetated wetland coastal islands. Extensive stretches of mangroves, coral reefs, and sea grass beds form an eco-system for many ocean animals and species. Not only do these coastlines and oceans have significant value in terms of giving shelter to wildlife, but they also provide cultural value, natural landscape benefits, and archeological value. Studies have pointed out that the Indian Ocean is home to a host of marine eco-systems, offering habitats to various ocean animals and birds. Given the richness of the Indian Ocean's eco-system, the impacts could vary, with differing intensities depending on the context and eco-system characteristics. Hence, before implementing any proposed offshore wind project, there should be careful scrutiny of its environmental and social impacts.

The proposed offshore wind projects could be distortionary in many ways. They could disturb the marine biodiversity, create noise pollution for marine habitats, pollute the ocean water at various stages of project development, such as construction, operation, maintenance, and decommissioning, and disturb marine habitats and their residents' breeding and feeding seasons and grounds.

In both the Bay of Bengal and the Arabian Sea, there are a number of marine protected areas (MPAs), which constitute important ecologically sensitive areas for any developmental projects (Singh 2020). Table 3 captures the major marine national parks and sanctuaries in India. Some of these areas are fragile in nature; hence, the protection of these areas should receive the utmost priority. Many of these MPAs are host to a number of mangrove species, for example Bhitar Kanika Sanctuary and Gahirmata Marine Sanctuary. Considering the importance of mangroves, the Government of India has identified 31 mangrove areas for intensive conservation (Singh 2003). There has been apprehension that offshore wind projects could adversely affect mangroves. For instance, the proposed project in the Gulf of Khambat will affect stretches of mangroves that have already faced degradation for the last couple of decades (Aggarwal 2018). In fact, the proposed project site of the Gulf of Khambhat is home to a variety of plants, animals, and birds. Developing such projects without adequate measures in hand could further accentuate the degradation of mangroves and exert an adverse impact on the marine biodiversity in the region. A report of the Gujarat Ecology Commission echoed this. The Gujarat Ecology Commission warned that, due to the strategic geographical location of the Gulf of Khambhat, it is becoming increasingly vulnerable to human-led activities, such as rapid industrialization, the fast building of coastal infrastructures, and other developmental projects, such as ports, oil terminals, and so on, which continue to endanger and disturb the ecological balance (Aggarwal 2018). Hence, the proposed project could further jeopardize the ecological balance in the area.

Similarly, some of these areas are rich in coral reefs, which are known dynamic eco-systems and help significantly in protecting the coastlines from erosion. For instance, the Gulf of Mannar, Gulf of Kutch, and Palk Strait are rich in coral reefs and represent diverse ocean eco-systems. Some of these areas are prospective sites for offshore project development too. While the impact of offshore wind energy on coral reefs is unclear at best, considering the other negative environmental and ecological impacts of these projects, it is pivotal to conduct a detailed EIA to avoid probable impacts on coral reefs.

Similarly, MPAs are home to various sea animals and are known as fish boxes, which are closed for certain periods of time as part of the restrictions of the management regime. Certain marine biodiversity areas with estuaries serve as the breeding and feeding grounds for sea animals. For instance, the estuaries of Gujarat provide feeding grounds for whale sharks. Both the Arabian Ocean and the Bay of Bengal are home to a variety of sea animals. For instance, dugongs live along the Gujarat coastline. Similarly, Indian coastlines act as a breeding ground for sea turtles, for which the coast of Saurashtra is a hatching ground. Gahirmatha Beach in Odisha is the largest known mass nesting site for Olive Ridley turtles. Chilika Lake is famous as a wintering ground for migratory birds. Given this richness of the Indian Ocean as a home to a variety of sea animals and birds, offshore wind projects could pose major risks for their habitats. Enough evidence of such negative impacts of these projects on ocean ecosystems and ocean biodiversity exists in other countries. For instance, the proposed project site in Gujarat is the ground for hundreds of plant species and for sea animals, and migratory birds, and non-migratory birds. Without taking adequate measures, the project could impose significant negative impacts (Aggarwal 2019). For instance, these projects could block the migratory path of birds, and collisions with wind turbines could kill or injure birds. There have been instances in which offshore wind projects have generated great risks for seabird colonies. For instance, the Royal Society for Protection of Birds (RSPB) challenged the government’s decision to deploy wind farms in Scotland.

Table 3: Major Marine National Parks and Sanctuaries in India

Gulf of Kachchh Marine National Park, Gujarat	Gulf of Mannar Marine National Park, Tamil Nadu
Gulf of Kachchh Marine Sanctuary, Gujarat	Pulicat Lake Bird Sanctuary (Tamil Nadu and Andhra Pradesh)
Malvan Marine Sanctuary, Maharashtra	Point Calimere Wildlife and Bird Sanctuary, Tamil Nadu
Bhitar Kanika Sanctuary, Odisha	Coringa Wildlife Sanctuary, Odisha
Gahirmata Marine Sanctuary, Odisha	Krishna Wildlife Sanctuary, Andhra Pradesh
Chilka Lake Wetland System, Odisha	Sunderban Tiger Reserve National Park, West Bengal
Holliday Island Wildlife Sanctuary, West Bengal	Sajnakhali Wildlife Sanctuary, West Bengal.

Apart from all these ecological impacts, the noise that these projects create could disturb the marine ecology and generate harmful effects. Noises emanating from construction sites could affect fishes and other sea animals and change their behavior. Projects should employ advanced technologies to reduce the noise by using a soft-start or ramp-up procedure (OSPAR Commission 2008). Radiation from these plants, such as electromagnetic and heat radiation, could negatively affect marine animals. Table 4 captures the mapping of key environmental impacts based on the expert consultation.

Table 4: Mapping of the Key Environmental Impacts

	Stages in the Project Life and Possible Impacts				
Impacts/Stressor Types	**Construction**	**Operation**	**Maintenance**	**Transportation**	**Decommissioning**
Habitat loss	***	**	**	**	***
Disturbing sea birds' feeding areas	***	**	**	**	***
Disturbing fish spawning areas	***	**	**	**	***
Injury or mortality to species	**	***	*	**	***
Risks of collision of birds	*	***	*	*	*
Community structure of marine species	**	**	*	**	**
Relocation and migration of marine species	***	**	*	**	***
Disturbance of animal behavior	***	***	*	**	***
Noise pollution	***	**	***	*	***
Ocean water pollution	***	**	**	*	***
Visual impacts	**	***	**	*	**

* represents a negligible impact, ** represents a moderate impact, and *** represents a high impact.

Source: Author's construct based on inputs from experts.

5.2 Social Impacts of Offshore Wind Projects

The social impacts largely are concerned with the possibility that these projects will adversely affect the livelihood of fishing communities by reducing the fish catches. Even the National Offshore Wind Energy Policy of Government of India and the FOWIND (2017) study clearly recognized the importance of fishing as a major source of livelihood for Indian coastal communities. Studies have reported that there are short-term and long-term effects of the development of offshore wind energy on the livelihood of fishing communities. However, the understanding of the complex linkage between wind energy's development and its impacts on fish behavior and fishing communities' livelihood is, at best, poor in India.

In India, nearly 15 million people draw their livelihood from fishing and fishing-related activities, and fishing contributes close to 5% of the GDP and 10% of foreign exchanges. Out of the total fishing production in the country, sea fishing constitutes 45%. Tamil Nadu, which is one of the designated states for offshore wind energy projects, is home to 600 marine fishing villages, and nearly 1.2 million people earn their livelihoods directly from fishing. Both Tamil Nadu and Gujarat rank as the states with the largest amount of marine fish production in the country. While the livelihood of fishing communities is already under threat from ocean pollution and climate change considerations (Srinivasan 2019), the proposed offshore wind energy projects could further accentuate the problem.

Impacts on fishing could occur in multiple ways. Fishing through trawling could be damaging to the structure of offshore wind plants as trawling can cause damage to the seafloor and seabed. Often, in the case of floating turbines, trawling could damage the anchorage of moorings. Because of these effects, trawling is not permissible in offshore wind areas. This can create considerable hardship for fishing communities. If they lose their trawling ground, they lose their fish catches. In addition, these projects could disturb the fish habitat, and the noise that these wind farms create could be harmful to the fish population. Certain parts of the ocean, such as the Bay of Bengal, are already suffering from overfishing, aggravating the problem (Singh 2020).

It is also important to recognize that marine fishery resources have specific characteristics that make them difficult to monitor and manage, hence compounding the problem of mapping of wind farms' impacts. For instance, they continue to migrate, largely dependent on the sea conditions, so it is challenging to monitor and assess them clearly. All these issues pose additional challenges to the assessment of offshore wind projects' impact on fishing and the devising of appropriate strategies. While the National Wind Energy Policy prescribes the identification of fishing grounds and the relocation of such grounds, given the volatility in the migration character of sea fishes, such relocation is difficult to execute.

Offshore wind projects could impair the visual and scenic beauty of the sea and have a negative impact on ocean-based tourism. The visual impacts depend on the location of the wind farms in relation to the coast. Studies in the context of other countries have pointed to the presence of such impacts (Ladenburg 2009; Maslov, Claramunt, Wang, and Tang 2017). While there has been considerable emphasis on coastal tourism, through schemes such as *Sagarmala*, it may conflict with nature though the location of offshore wind energy projects. The Indian coasts serve as a major source of tourism and constitute a major source of revenue in India.

It is evident from the mapping of impacts that they differ in their intensities across various stages of the project life and for different categories of environmental and social elements. Given the importance of ocean ecosystems and the ecological significance of marine biodiversity and species, developmental projects like offshore wind energy require detailed scrutiny and assessment. This becomes more pronounced as the policy envisages public–private partnerships, which often give less importance to such environmental and social considerations. Further, while the most substantial study, which FOWIND (2017) carried out, recognized the possible environmental and social impacts of such projects, it did not consider these impacts as crucial factors for offshore wind energy development in the country. The next section offers some possible pathways for the development of such energy assets.

6. OFFSHORE WIND ENERGY INFRASTRUCTURE IN INDIA: MAPPING THE FUTURE PATHWAYS

While the previous section mapped the possible environmental and social impacts of offshore wind energy projects, this section suggests some possible pathways.

Need to Develop Robust EIA and SIA

There is a need to develop robust and detailed environmental impact assessment (EIA) and social impact assessment (SIA) guidelines, which are crucial for understanding the possible environmental and social impacts and the management practices necessary to minimize such threats. While the National Wind Energy Policy 2015 refers to EIA and the possible impacts on fishing communities, detailed guidelines are lacking. Besides, the policy is silent regarding the institutional mechanism that it is necessary to develop to carry out such assessments, particularly at the sub-national scale. The scale and timing of such impacts are also quite pertinent given that offshore wind energy technologies are new and the impacts are largely unknown. It is also important to identify localized impacts and undertake the required action plans. In many instances, the detailed environmental constraints have a strong link to the adopted technological approaches. Hence, efforts to carry out environmental impact assessments devoid of technological solutions will be suboptimal.

Detailed Marine Spatial Planning

Projects require a detailed marine spatial planning exercise to assess the possible environmental and social impacts. Most European countries carry out detailed marine spatial planning, which consists of developing a good understanding of the environmental constraints, conducting extensive stakeholder surveys, and so on. These are more pronounced in a country like India, where local community protests are very strong and importantly competing interests exist for the use of marine spaces exist. There is historical evidence that many power projects suffer delays or cancellation due to a poor understanding of their environmental and social impacts.

Spatial planning could also involve implementing the necessary action plans. For instance, action plans are needed to identify birds' migratory paths and avoid the construction of such projects in those paths, to produce technical designs for wind farms, such as grouping turbines to avoid flying paths, to increase the visibility of rotor blades with colors to reduce collisions, and so on. Similarly, the deployment of advanced technologies can reduce the noise by using the soft-start or ramp-up procedure (OSPAR Commission 2008). Necessary steps, such as the use of suitable cables, shielding of cables, and burial of cables at a safe depth, can reduce such negative impacts. While technological developments could help to address some of the spatial issues of the development of offshore wind energy projects, it is important to carry out stakeholder consultations at every stage of project development to minimize frictions between different stakeholders in the use of marine areas and spaces.

Detailed Stakeholder Mapping

To assess the social impacts, it is pertinent to carry out detailed stakeholder surveys. For instance, fishing constitutes an important source of livelihoods in India. It is important for the proposed projects to start engaging with fishing communities from the very beginning of the project. Detailed engagement with various fishing communities and entities such as local fishing cooperatives, the National Coastal Zone Management Authority, the Department of Animal Husbandry, Dairying, and Fisheries, the State

Fisheries Department, and so on is crucial. This could build confidence and reduce the uncertainties.

Similarly, carrying out environmental impact assessment involves engaging with the local stakeholders in both social and environmental matters and taking them into confidence in decision making. Given that the thrust of these projects is on private development, poor and fragmented community engagement could generate adverse repercussions in the long run. While social issues, such as livelihoods, are more direct and immediate, the environmental issues will largely emerge over different phases of project operation. Inclusive, participatory, and well-informed stakeholder engagement is crucial for these projects.

These are a few action plans that could reduce the environmental and social impacts of offshore wind energy project development. For instance, the FOWIND study (2017) identified an extended list of stakeholders to consult when carrying out the EIA.

Transiting from Management to Governance

As it is likely that primarily private actors will develop and manage offshore wind energy infrastructures, it is necessary for sustainable ocean governance to move beyond the management structures to governance systems involving public, private, and other actors, such as cooperatives, informal groups and civil society groups. A mix of management and a well-governed system could deliver the optimal outcomes. Governance is crucial as there are competing interests among varying stakeholders in extracting marine resources of different forms. While, on the one hand, maintaining the marine ecosystem and retaining its functionality are crucial, on the other hand, there has been increasing pressure on marine resources through various policy initiatives, such as deep ocean missions.

It is also important to focus on creating local jobs through these interventions. Studies have pointed out that offshore wind energy projects generate many sustainable jobs in various segments of the supply chain. For instance, the GWEC's (2021) estimates suggested that offshore wind projects on average generate about 17 person-years per MW over the 25-year lifetime of the project. However, given the Indian context and the heavy reliance on the ocean for livelihoods, it is important to provide those who are losing their livelihoods with some alternative employment opportunities.

7. CONCLUDING REMARKS

In the basket of renewables, offshore wind energy is emerging as a promising energy infrastructure worldwide, with far-reaching potential to meet the burgeoning energy demand. Offshore wind energy is promising as an alternative source of energy for a country like India, which continues to be land deprived and increasingly faces difficulties in acquiring land for energy. Considering the potential, the available technology, and the cost, the country has set medium-term and long-term targets of deploying 5 GW of offshore wind energy by 2022 and 30 GW of offshore wind energy by 2030. While some scholarly efforts in the Indian context have analyzed various aspects of offshore wind energy development, there is a dearth of studies understanding and analyzing the associated environmental and social challenges of such infrastructure deployment.

The development of the necessary policy and institutional framework governing offshore wind energy development has taken place and includes provisions to assess the environmental impact and the effects on livelihoods. However, the policy does not explicitly mention the institutional mechanisms that it is necessary to create at the sub-national scale. The policy document also does not refer to other environmental laws, regulations, and guidelines that are applicable to such projects.

While the full-scale impact will be apparent after projects' operationalization, drawing from the international experiences and expert consultation, the paper identified a host of possible environmental and social impacts. This mapping is more pertinent given that the EIA Notification of 2006 does not cover most of the renewable energy in India under its ambit and most of the state pollution control boards tag renewable energy projects such as solar and wind projects as "green." There has been apprehension that offshore wind projects could adversely affect the marine protected areas and their ecosystems. It emerged from the analysis that mangroves, for instance, could suffer adverse impacts, particularly from the proposed project in the Gulf of Khambhat, which has stretches of mangroves. Developing such projects without implementing adequate measures could accentuate the degradation of mangroves (Aggarwal 2018). Similarly, rich coral reef sites exist in the proposed offshore wind project states. For instance, the Gulf of Mannar, Gulf of Kutch, and Palk Strait are rich in coral reefs. Though the impacts on coral reefs are unclear, it is necessary to undertake precautionary measures to reduce the possible negative impacts. Offshore wind projects could pose major risks to the habitats of ocean animals and birds. For instance, the proposed project site in Gujarat is the ground for hundreds of plant species and a place for sea animals, and migratory, and non-migratory birds (Aggarwal 2019). Without adequate measures, the project could exert strong negative impacts. For instance, the impact on migratory birds could be significant. It could be in the form of blocking their migratory paths or killing birds due to collision with wind turbines. Apart from all these impacts, the noise and radiation emanating from these plants, such as electromagnetic and heat radiation, could negatively affect marine animals. They could create harmful effects on fishes and other sea animals and may change their behavior.

The social impacts are largely in the form of adverse impacts on the livelihood of fishing communities. The impacts on fishing could occur in multiple ways. Fishing through trawling could be damaging for the structure of the offshore wind plants; hence, offshore wind areas usually ban trawling. This can create substantial hardship for fishing communities. The noise that these wind farms create could also be harmful for the fish population. More importantly, marine fishery resources have specific characteristics that makes them difficult to monitor and manage. For instance, fish continue to migrate frequently, largely affected by the sea conditions. While the National Wind Energy Policy prescribes the identification of fishing grounds and their relocation, given the fishing characteristics, it is difficult to execute such relocation. The overall mapping revealed that the impacts would be different at different stages of project development and operation. Hence, careful scrutiny and analysis are necessary before implementing such projects.

The paper offers some possible pathways to minimize these impacts. There is a need to develop robust and detailed environmental impact assessment (EIA) and social impact assessment (SIA) guidelines. The assessments should take localized effects into consideration. It is necessary to create adequate local-level capacities to deal with such impacts. The emphasis should be on detailed marine spatial planning exercises. Understanding environmental constraints is important. In the Indian context, it is crucial to conduct detailed stakeholder surveys, including all possible stakeholders. Finally, there is a need to make appropriate action plans. For instance, to reduce the impacts of offshore wind projects on migratory birds, it is important to identify birds' migratory paths, increase the visibility of motor blades, and so on.

Though the assessment that this study carried out offers some direction for the offshore wind energy development in the country, it has limitations as it did not perform an in-depth survey to identify the localized impacts of such project development. Given the diversity and contextual heterogeneity, it is important to understand the possible impacts of such projects on the ground. Context-specific impact assessment that considers the heterogeneity of ocean ecology and ocean biodiversity would highlight the context-specific challenges. This opens up new areas of research and analysis for the future.

REFERENCES

Aggarwal, M. 2018. "Clean versus Green: Will India's Offshore Wind Energy Push Threaten Biodiversity?" https://india.mongabay.com/2018/04/clean-vs-green-will-indias-offshore-wind-energy-push-threaten-biodiversity/.

———. 2019. "Environmental Damage Could Have Offshore Wind Farms Clearance Cancelled." *The Wire*. https://thewire.in/environment/environmental-damage-could-have-offshore-wind-farms-clearance-cancelled.

Bailey, H., K. L. Brookes, and P. M. Thompson. 2014. "Assessing Environmental Impacts of Offshore Wind Farms: Lessons Learned and Recommendations for the Future." *Aquatic Biosystems* 10 (8). doi:10.1186/2046-9063-10-8.

Bergström, L., F. Sundqvist, and U. Bergström. 2013. "Effects of an Offshore Wind Farm on Temporal and Spatial Patterns in the Demersal Fish Community." *Marine Ecology Progress Series* 485: 199–210. doi:10.3354/meps10344.

Bhatti, J. 2021. "No Offshore Wind Project Has Commenced in India: Are We on Track for 30 GW by 2030?" *Down to Earth*. https://www.downtoearth.org.in/blog/energy/no-offshore-wind-project-has-commenced-in-india-are-we-on-track-for-30-gw-by-2030--78982.

Ciara, E., T. Garcia, C. Ortega, and L. Richmond. 2020. "Social Impacts to Other Communities that Experienced Offshore Wind." In *California North Coast Offshore Wind Studies*, edited by M. Severy, Z. Alva, G. Chapman, M. Cheli, T. Garcia, C. Ortega, N. Salas, A. Younes, J. Zoellick, and A. Jacobson. Humboldt, CA: Schatz Energy Research Center. schatzcenter.org/pubs/2020-OSW-R20.pdf.

FOWIND. 2017. *From Zero to Five GW—Offshore Wind Outlook for Gujarat and Tamil Nadu (2018–2032)*. FOWIND.

Global Wind Energy Council (GWEC). 2020. *Global Offshore Wind Report 2020*. Belgium: Global Wind Energy Council.

———. 2021. *Wind Power and Green Recovery*. Belgium: Global Wind Energy Council.

International Energy Agency (IEA). 2018. *Off-shore Energy Outlook*. Paris: International Energy Agency.

International Renewable Energy Agency (IRENA). 2020a. *Countries Raise the Sails on Offshore Renewable Sector*. October 2020. International Renewable Energy Agency, Abu Dhabi, United Arab Emirates.

———. 2020b. *Fostering a Blue Economy: Offshore Renewable Energy*. December 2020. International Renewable Energy Agency, Abu Dhabi, United Arab Emirates.

Jayaram, D. 2016. "Sustainable Marine Resource Governance in Indian Ocean Region." *Climate Diplomacy*. Accessed on 18 February 2021. https://climate-diplomacy.org/magazine/environment/sustainable-marine-resource-governance-indian-ocean-region.

Kota, S., S. B. Bayne, and S. Nimmagada. 2015. "Off-shore Wind Energy: A Comparative Analysis of UK, USA and India." *Renewable and Sustainable Energy Reviews* 41: 685–94.

Kumar, J C R., D.V. Kumar, D. Baskar, B.M. Arunsi, R. Jenova, R, and M.A. Maijid. 2020 “Offshore wind energy status, challenges, opportunities, environmental impacts, occupational health and safety management in India, Energy and Environment, 0(0): 1–39.

Ladenburg, J. 2009. “Visual Impact Assessment of Offshore Wind Farms and Prior Experience.” *Applied Energy* 86: 380–7.

Legal Initiative for Forest and Environment. 2014. *Legal Framework for Conservation of Coastal and Marine Environment of India: A Review*. CMPA Technical Series No. 02. Indo-German Biodiversity Programme. New Delhi: GIZ India.

Lindeboom, H. J., H. J. Kouwenhoven, M. J. N. Bergman, S. Bouma, S. Brasseur, R. Daan et al. 2011. “Short-Term Ecological Effects of an Offshore Wind Farm in the Dutch Coastal Zone: A Compilation.” *Environmental Research Letter* 6: 35101. doi:10.1088/1748-9326/6/3/035101.

Mani, S., and T. Dhingra. 2013a. “Critiques of Off Shore Wind Energy Policies of the UK and Germany—What Are the Lessons for India.” *Energy Policy* 63: 900–9.

———. 2013b. “Off Shore Wind Energy Policy in India—Key Factors to Be Considered.” *Energy Policy* 56: 672–83.

———. 2013c. “Policies to Accelerate Growth of Offshore Wind Energy in India.” *Renewable and Sustainable Energy Reviews* 24: 473–82.

Maslov, N., C. Claramunt, T. Wang, and T. Tang. 2017. “Evaluating the Visual Impact of an Off-shore Wind Farm.” *Energy Procedia* 105: 3095–100.

Nagababu, G., S. S. Kachhwaha, N. K. Naidu, and V. Savsani. 2017b. “Application of Reanalysis Data to Estimate Offshore Wind Potential in EEZ of India Based on Marine Ecosystem Considerations.” *Energy* 118: 622–31. doi:10.1016/j.energy.2016.10.097.

Nagababu, G., S. S. Kachhwaha, and V. Savsani. 2017a. “Estimation of Technical and Economic Potential of Offshore Wind along the Coast of India.” *Energy*. 10.1016/ j.energy.2017.07.032.

OSPAR Commission. 2008. “Assessment of Environmental Impacts of Offshore Wind Farms.” https://qsr2010.ospar.org/media/assessments/p00385_Wind-farms_assessment_final.pdf.

Parsons, G., J. Firestone, L. Yan, and J. Toussaint. 2020. “The Effect of Offshore Wind Power Projects on Recreational Beach Use on the East Coast of the United States: Evidence from Contingent-Behavior Data.” *Energy Policy* 144: 11. doi: 10.1016/j.enpol.2020.111659.

Phadke, A. et al. 2012. *Reassessing Wind Potential Estimates for India: Economic and Policy Implications*. Lawrence Berkeley Labs, International Energy Studies, Environmental Energy, Technologies Division.

Randall-Smith, B. 2020. “India Prepares to Tender 1 GW.” Accessed 30 October 2020. https://www.4coffshore.com/news/india-prepares-to-tender-first-1-gw-nid16998.html.

Roy, A. 2019. *Blue Economy in Indian Ocean: Governance Perspectives for Sustainable Development in the Region*. Observer Research Foundation Occasional Paper. https://www.orfonline.org/research/blue-economy-in-the-indian-ocean-governance-perspectives-for-sustainable-development-in-the-region-47449/.

Singh, H. 2003. "Marine Protected Areas in India." *Indian Journal of Marine Science* 32 (3): 226–33.

Singh, A. 2020. "Towards an Integrated 'Blue Economy' Framework in the Bay of Bengal." *ORF Issue Brief*, October 2020.

Sivakumar, K., V. B. Mathur, and Anant Pande. 2013. "Coastal and Marine Protected Areas in India: Challenges and Way Forward." In *ENVIS Bulletin: Wildlife & Protected Areas*, Vol. 15, edited by K. Sivakumar, 292–8. Dehradun, India: Wildlife Institute of India.

Srinivasan, R. 2019. "Trawling for a Sustainable Livelihood." *Business Line*, 17 April 2019.

Thapar, S. 2017. *Addressing Land Issues for Utility Scale Renewable Energy Deployment in India*. TERI School of Advanced Studies, New Delhi, India.

Thompson, P. M., G. D. Hastie, J. Nedwell et al. 2013. "Framework for Assessing Impacts of Pile-Driving Noise from Offshore Wind Farm Construction on a Harbor Seal Population." *Environmental Impact Assessment Review* 43: 73–85.

Voyer, M., and J. V. Leeuwen. 2019. "'Social License to Operate' in the Blue Economy." *Resources Policy* 62: 102–13.

Wei, Y., Q., Zou, and X. Lin. 2021. "Evolution of Price Policy for Offshore Wind Energy in China: Trilemma of Capacity, Price and Subsidy." *Renewable and Sustainable Energy Reviews* 136: 1–13.

World Wide Fund for Nature (WWF). 2014. *Environmental Impacts of Offshore Wind Power Production in North Sea*. WWF, Norway.