WORLD BANK GROUP

Offshore Wind Development Program

OFFSHORE WIND ROADMAP FOR SRI LANKA

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EXECUTIVE SUMMARY

This roadmap provides strategic analysis of the offshore wind development potential in Sri Lanka, considering the opportunities and challenges under different offshore wind growth scenarios. It is intended to provide evidence to support the Government of Sri Lanka in establishing policy, regulations, processes, and infrastructure to successfully deploy offshore wind.

The roadmap report was initiated by the World Bank Group under its Offshore Wind Development Program, which aims to accelerate offshore wind development in emerging markets. The roadmap was funded by the Energy Sector Management Assistance Program (ESMAP) with support from the World Bank's blue economy program, PROBLUE.

RATIONALE FOR OFFSHORE WIND IN SRI LANKA

Sri Lanka has good natural conditions for offshore wind and there is already private sector interest in developing projects. Sri Lanka has an opportunity to use this domestic renewable energy resource as part of its transition to net-zero carbon and to help reduce the economic burden from fossil fuel imports. The main drivers for developing offshore wind in Sri Lanka include:

- **Decarbonization**: The Government of Sri Lanka has set a goal of 70 percent of electricity generation from renewable sources in 2030 and to achieve carbon neutrality in electricity generation by 2050. Furthermore, Sri Lanka's Nationally Determined Contributions (NDCs) under the Paris Agreement include a commitment of no capacity addition of coal power plants. In 2021, around 48 percent of Sri Lanka's electricity was supplied by renewable resources (almost entirely hydro) and the rest of the supply was dominated by oil and coal-fired thermal power. Electricity demand is also expected to grow by an annual rate of five percent for the coming 20 years. As individual onshore wind and solar PV projects in Sri Lanka to date have tended to be small, and land is a precious resource, their deployment rate could be insufficient to fully meet the 2030 target. Offshore wind has the potential to provide a large-scale contribution to help achieve the government's decarbonization targets, especially in the longer term.
- **Security of supply**: All of Sri Lanka's hydrocarbon fuels are imported. This places a large risk on the security of supply and affordability of the majority of the country's electricity generation. This risk was realized in 2022, with fuel shortages and high prices. Transitioning to domestic sources of energy, particularly renewable energy, will provide greater energy security. Sri Lanka's +50 gigawatts (GW) of offshore wind resources offer an abundant domestic supply of energy and could help improve the country's energy security.
- **Economic benefits**: The country's dependence on imported fossil fuels places a large burden on its foreign reserves; the depletion of these reserves led to the economic crisis in 2022. Transitioning to domestic sources of energy, particularly renewable energy, can help to reduce the burden and reduce the trade imbalance, thereby benefitting the economy. Furthermore, the development

of offshore wind could provide a substantial contribution to the economy; for example, over the lifetime of a 500 megawatt (MW) offshore wind farm, the Sri Lankan economy could benefit from approximately US$570 million of gross value added (GVA) through local investment and employment. This could build on Sri Lanka's maritime heritage and marine capabilities, helping to diversify the local industry, shipyards, and port facilities.

- **Energy exports**: An electrical interconnector between Sri Lanka and India could benefit both countries and with the addition of large-scale offshore wind, Sri Lanka could become an energy exporter, particularly at times where supply exceeds local demand. This would provide a new revenue stream for the country and, as more local capacity is added, this export potential and revenue could increase. The sale of power to consumers connected to the Indian grid (e.g., Bangladesh) could also be considered and would open up more offtake possibilities. In the future, excess electricity generation could also be used to produce green hydrogen and other zero-carbon energy vectors such as ammonia. These products could be sold to decarbonize maritime transportation, for example. The economics of this opportunity will need to be assessed as green hydrogen technology, and the markets for it, mature. However, it is likely to be a longer-term opportunity and unlikely to feature in the business case for the country's first projects.
- **Regional cooperation**: India is exploring its offshore wind resources and targets the deployment of 30GW of capacity by 2030. The Indian state of Tamil Nadu, which has India's best resources, is the closest to Sri Lanka and, during 2023, the Government of India intends to award seabed leases for at least 4GW capacity in this state, with projects expected to commence construction between 2028 and 2030. Regional cooperation between these two future markets could be mutually beneficial. Unless significant interconnector capacity with India is built over time, Sri Lanka's total market size will be relatively small (<5GW) by the industry's standards but, when considered in combination with the development in Tamil Nadu, it becomes more attractive for developers, as well as port and supply chain investment. This could help to reduce the costs of projects in both countries and increase local economic benefits in Sri Lanka. Similarly, development in Sri Lanka could provide additional market opportunities for the Indian supply chain.
- **Avoiding land use**: Although Sri Lanka is a relatively large island, it still has limited space and there are many competing uses for land, particularly agriculture which is an important sector for the island's economy. Unlike large-scale solar PV and onshore wind projects, offshore wind can avoid using large areas of land, reducing the demand for onshore renewable energy sites.

SRI LANKA'S OFFSHORE WIND POTENTIAL

Sri Lanka has good conditions for offshore wind and its locational potential is estimated at 56GW. This includes 27GW of fixed offshore wind in shallow waters (less than 50 meters) and 29GW of floating offshore wind in deeper waters (between 50 and 1,000 meters). Analysis for this roadmap used existing spatial data to characterize Sri Lanka's offshore wind resources and the potential constraints to development. It assessed a wide range of environmental, social, and technical issues to identify technically attractive initial exploration areas that, based on the data available, are likely to have lower negative impacts associated with development.

There are three broad areas suitable for offshore wind development, but the western and southern coasts have the most energetic wind speeds and suitable technical conditions. The map in Figure ES.1 shows these three areas and Table ES.1 provides a summary of their offshore wind potential.

Areas with the highest environmental or social sensitivities have been excluded to avoid unacceptable adverse impacts. There are many coastal and marine areas that have significant environmental, social, and technical sensitivities that have been categorized as 'restriction zones.' Offshore wind development may be possible in these zones, but it is likely that substantial measures will be required to manage and mitigate adverse impacts.

FIGURE ES.1: THE THREE POTENTIAL AREAS FOR OFFSHORE WIND, INCLUDING THE PRIORITY AREAS TO BE CONSIDERED FOR SRI LANKA'S FIRST OFFSHORE PROJECTS — MANNAR AND PUTTALAM.

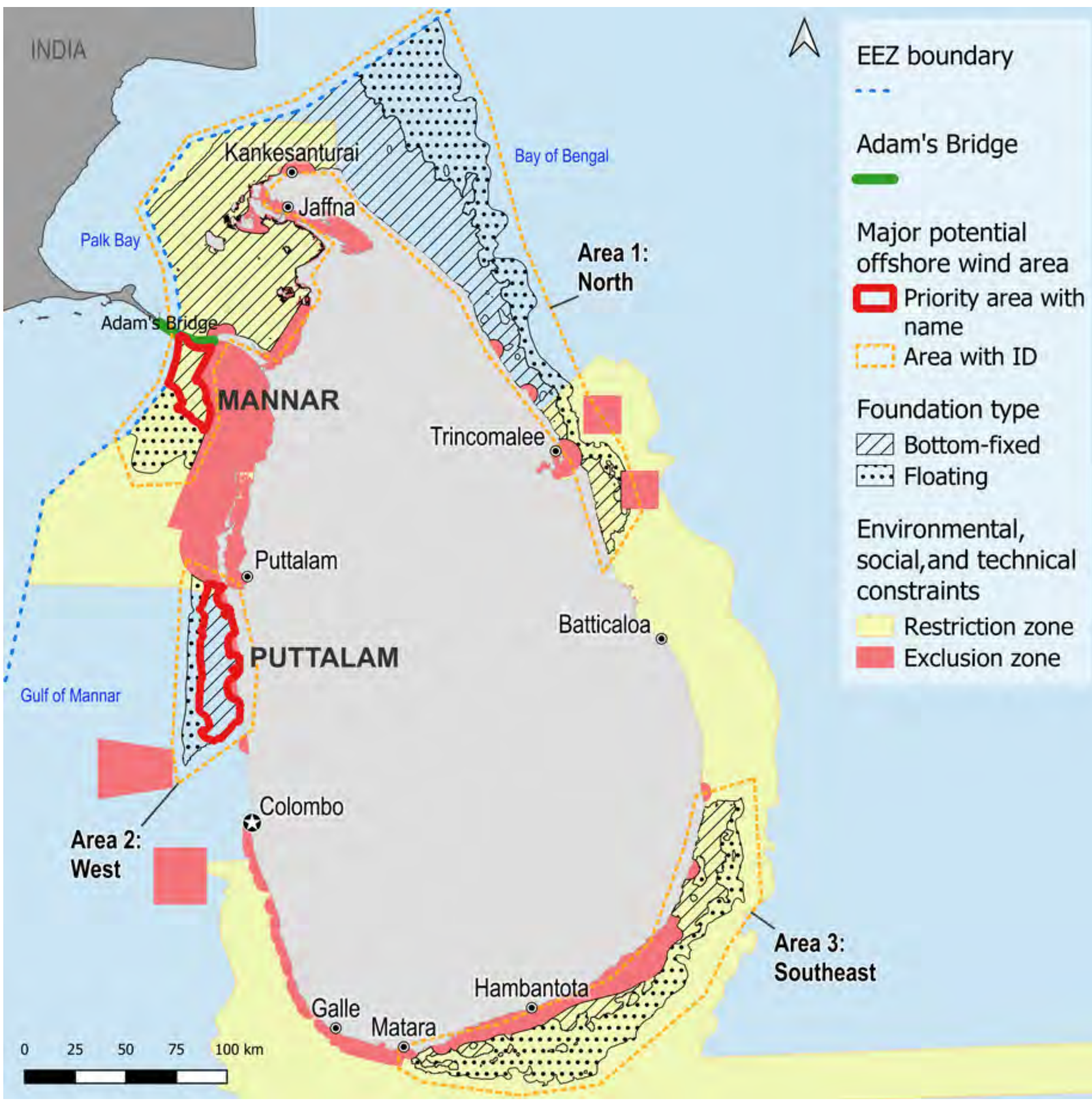


TABLE ES.1: CHARACTERISTICS OF THE THREE POTENTIAL AREAS SUITABLE FOR OFFSHORE WIND DEVELOPMENT.

	Fixed Potential		Floating Potential		Typical Wind Speed at 150m
	km²	GW	km²	GW	m/s
Area 1: North	4,564	18	3,697	15	7-9
Area 2: West	1,027	4	624	2	7-8.5
Area 3: Southeast	1,336	5	2,947	12	7-9
TOTAL	**6,927**	**27**	**7,268**	**29**	

Not all 56GW of offshore wind potential will be developed due to practical and cost limitations. The estimate of 56GW is based on high-level analysis using existing spatial data and there are significant gaps in the data available. Future studies and research are needed to better understand the feasibility of offshore wind development in Sri Lanka's waters and fill these data gaps. As offshore wind capacity grows, the cumulative impact of multiple projects may limit further development. Furthermore, not all of the resource identified will be economically feasible, especially areas with lower wind speeds and deeper waters. Despite these challenges, even a small portion of the offshore wind resource identified in this roadmap could provide a significant contribution to Sri Lanka's energy mix and present a promising new opportunity for the country.

SCENARIOS FOR OFFSHORE WIND DEPLOYMENT

To illustrate possible development paths for offshore wind in Sri Lanka, two deployment scenarios have been developed — a low and a high growth scenario (see Table ES.2 for a summary). The purpose of these scenarios is to illustrate the potential effect of industry scale on cost, consumer benefit, environmental and social risks, and economic impact. The scenarios are based on feedback from stakeholders, assessments of the state of offshore development today, statements on the political aspirations of Sri Lanka, and an assessment of the overall potential for offshore wind in the country. They were not established or tested through power generation planning or modelling; the roadmap recommends this as another priority next step.

Under either scenario, by around 2030, Sri Lanka could commission its first offshore wind farms, developing the skills and experience needed for further expansion post 2030. Both scenarios will require close collaboration between public and private stakeholders and financial derisking from international donors and financial institutions.

It is recommended that the Government of Sri Lanka sets both short-term (2030) and long-term (2050) offshore wind targets and makes amendments to establish a supportive regulatory framework.

The two development scenarios are summarized as follows:

- **Low Growth Scenario.** The Low Growth Scenario assumes a modest deployment of offshore wind capacity, with 0.5GW by 2030, 1GW by 2040, and 2GW total by 2050. This would be the equivalent of five percent of Sri Lanka's generation capacity in 2030, and about six percent in 2040. An installed capacity of 500MW by 2030 is estimated to avoid between 0.85 and 1.0 million metric tons of CO_2 emissions per year and, over the lifecycle of the project, could support employment up to 25,000 full-time equivalent (FTE) direct and indirect employment for the local communities.

Assuming that appropriate derisking reduces the cost of capital and that climate funds or other concessional sources can be mobilized, the levelized cost of energy (LCOE) for a first 500MW project is estimated to be US$75 to 90 per megawatt hour (MWh). As the industry continues to mature and the experience of deploying offshore wind in Sri Lanka reduces risk for subsequent projects, the LCOE is expected to reduce for subsequent projects and could reach US$60 per MWh by 2050.

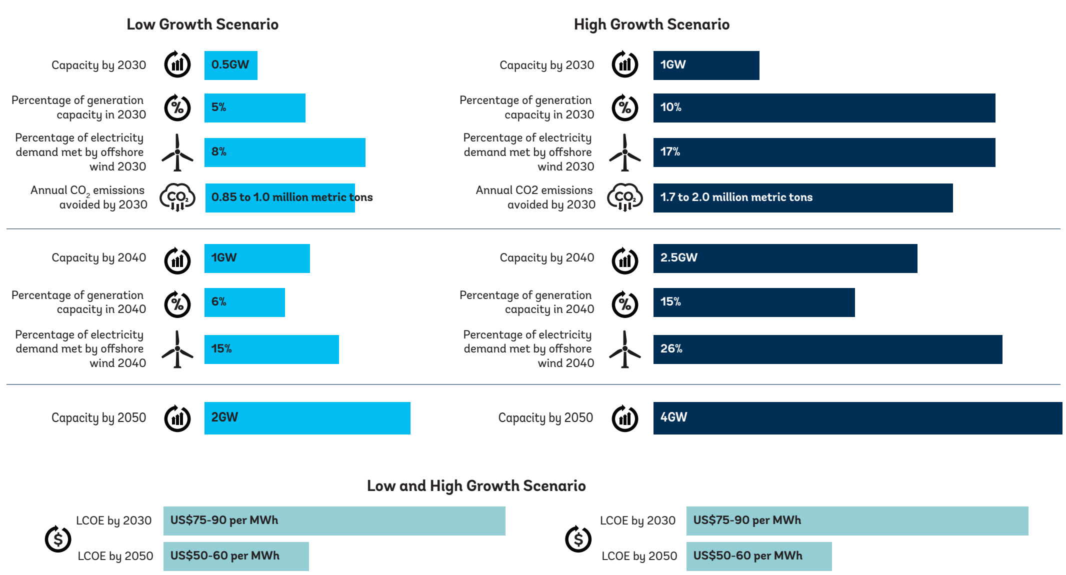
- **High Growth Scenario.** The High Growth Scenario assumes a larger accumulated installed capacity of 1GW in 2030, 2.5GW in 2040, and 4GW in 2050. This would be the equivalent of 10 percent of generation capacity in 2030, and about 15 percent in 2040. An installed capacity of 1GW by 2030 is estimated to avoid between 1.7 and 2.0 million metric tons of CO_2 emissions per year. Over its lifecycle 1GW of capacity could support employment up to 57,600 full-time equivalent (FTE) direct and indirect employment for the local communities.

  Since 1GW in 2030 is not sufficient to develop a local supply chain or gain economies of scale, the LCOE is expected to have the same range as for the Low Growth Scenario. Therefore, the benefits of larger deployment scale are likely to be seen after 2030. Post 2030, the LCOE could fall below US$60 per MWh by 2040 and be approximately US$50 per MWh by 2050.

  This scenario explores an interconnection link with India to export excess supply of electricity, as well as the production of green hydrogen in the longer-term. However, the economics of hydrogen generation would need to be assessed and depend, among other things, on technology and market developments. It also builds upon the idea of developing regional partnerships with China, Vietnam, and India to forego domestic supply chain constraints.

  To incentivize developers, the regulatory foundation for offshore wind in Sri Lanka must be streamlined to ensure transparent and competitive procurement routes. Furthermore, offshore wind should be incorporated into the long-term plan for expanding and reinforcing the transmission grid, taking into account the large scale of generation.

FIGURE ES.2: IMPACT OF OFFSHORE WIND IN SRI LANKA UNDER LOW AND HIGH GROWTH SCENARIOS, PERIOD 2030 TO 2050[1].



1 All figures are cumulative over the period 2030 to 2050, unless stated.

TABLE ES.2: OVERVIEW OF CUMULATIVE INSTALLED CAPACITY OF OFFSHORE WIND BY 2050 IN LOW AND HIGH GROWTH SCENARIO.

Offshore Wind	By 2030	By 2040	By 2050
Low growth (cumulative)	0.5GW	1GW	2GW
Bottom-fixed	0.5GW	1GW	1.5GW
Floating	0GW	0GW	0.5GW
High growth (cumulative)	1GW	2.5GW	4GW
Bottom-fixed	1GW	2GW	3GW
Floating	0GW	0.5GW	1GW

These two scenarios are hypothetical and were devised to demonstrate the impacts of government policy and actions. Therefore, the actual volumes of offshore wind installed in Sri Lanka will likely differ from these scenarios, both in terms of overall volume and phasing of installation. The high growth scenario should not be seen as a ceiling; should the government and other stakeholders follow the recommendations in this roadmap, there is potential for offshore wind to exceed this scenario, especially if a power interconnector with India is constructed.

CHALLENGES FOR DEVELOPING OFFSHORE WIND

While there are numerous challenges to developing offshore wind, these are common to many countries looking to deploy this technology for the first time. Some of the main challenges include:

- **The country is currently experiencing a severe economic crisis.** Unable to service its high debt costs, it announced a debt moratorium in April 2022. A large trade imbalance, exacerbated by expensive fossil fuel import costs, contributed to the crisis. Transitioning to renewable energy and thereby reducing fuel imports is expected to be an important action in the country's recovery.
- **Offshore wind has a higher cost than onshore wind and solar PV which could lower interest to start developing the offshore wind industry in a timely manner**. However, the realizable potential of onshore renewables may not be sufficient to meet the country's energy needs and decarbonization objectives by 2030 and beyond. Since offshore wind is an attractive option to ramp-up renewable generation in Sri Lanka, the development of both onshore and offshore renewables needs to be viewed holistically to reach the country's ambitious goals.
- **The domestic supply chain potential is limited.** Sri Lanka would therefore be highly dependent on international suppliers and developers for equipment and materials. The relatively small volume of offshore wind expected in Sri Lanka itself does not offer natural incentives to localize the supply chain significantly. However, the much larger volume of offshore wind development in the region offers potential for supply chain development in the region, including export opportunities for Sri Lanka.
- **Sri Lanka has no track record in offshore wind.** The country nonetheless has some capabilities in permitting and infrastructure development, as well as operation and maintenance (O&M) in related sectors, such as onshore wind and onshore electrical infrastructure, as well as offshore oil and gas exploration.

- **Port infrastructure needs to be properly assessed and upgraded.** The ports of Colombo and Hambantota can be upgraded to suit the requirements of offshore wind installation operations and specialized vessels. Trincomalee and Kankasenuthurai, however, would need major upgrades to be suitable. Capable ports could also allow the possibility of supplying the Indian offshore wind industry.
- **No dedicated offshore wind regulatory and institutional framework has been adopted.** The existing legal and regulatory system is primarily geared towards smaller scale, onshore renewable projects, which does not provide the needed clarity and certainty especially with regard to planning and permitting.
- **The transmission system requires strengthening in consideration of the offshore wind capacities to be added.** Adding large offshore wind farms each will have a significant impact on the transmission system. To be able to handle this ramp-up, there is need for proper planning and investments in grid infrastructure to provide the necessary upgrades.
- **Large CAPEX and insufficient and high cost of domestic capital are challenges to an affordable cost of electricity from Sri Lanka's first offshore wind developments**. The cost of capital from Sri Lankan banks is typically as high as 15 percent. Local banks will likely not be able to provide loans at the scale and with the tenor needed for offshore wind. International capital will be needed to finance projects and access to low-cost concessional finance will be essential to reduce the cost of energy of the first offshore wind projects.

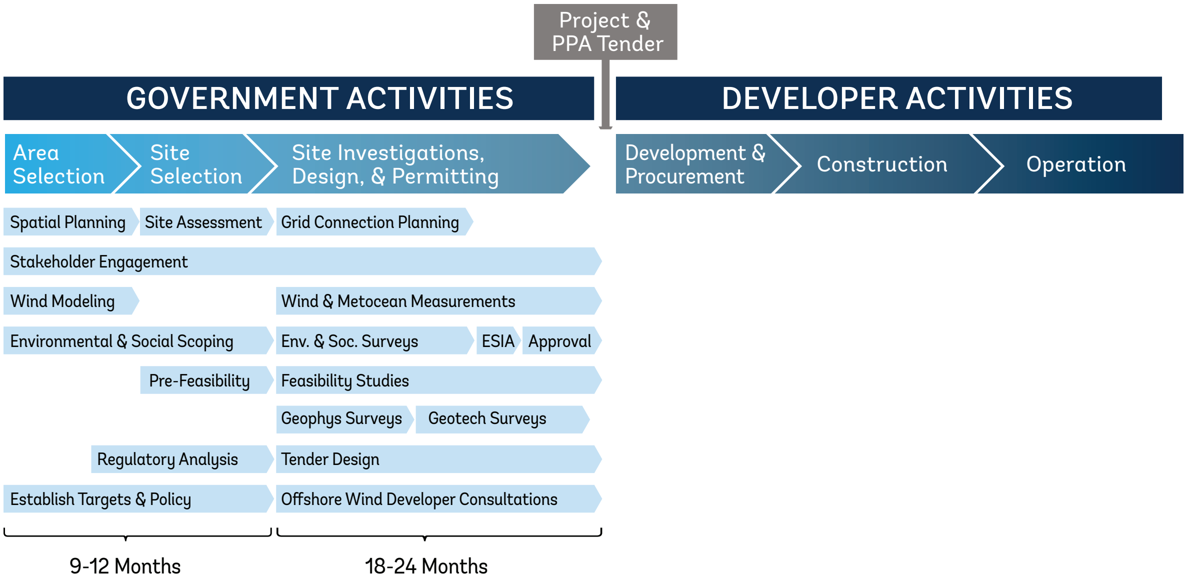
RECOMMENDED APPROACH

Although Sri Lanka has a clear opportunity to deploy offshore wind generation, there are important technical and economic challenges and risks which can make the opportunity less attractive to investors and project developers. The overall market opportunity is relatively small, which could make it more difficult to attract capable, experienced project developers to Sri Lanka. Developers are likely to include a premium to cover the risks and limited opportunity, and this would increase the cost of electricity. Derisking the investments to the extent possible is therefore critical.

For these reasons it is recommended that the Government takes a proactive role in the planning and delivery of offshore wind projects. It should do this by carrying out early-stage development activities and providing greater regulatory and commercial certainty. This will reduce the risk to investors, making the opportunity more attractive, and help to reduce costs. It will also provide time for the country's economy to recover before inviting investors to enter Sri Lanka. Further derisking instruments, including guarantees, will likely be required to attract the required capital at an affordable rate.

The development of offshore wind projects takes considerably longer than for onshore renewable energy projects. To avoid delays and higher costs, it is also important to focus on quality and risk reduction to ensure that the data and development work can be relied upon by developers bidding into the future tender. Figure ES.3 summarizes the main phases in the development and delivery of an offshore wind project. It focuses on the government-led development and preparatory activities that need to occur before a project tender, along with an estimated timeline for this work.

FIGURE ES.3: REPRESENTATIVE TIMELINE FOR DEVELOPMENT WORK AHEAD OF A PROJECT TENDER COMPETITION.



PATHFINDER PROJECT

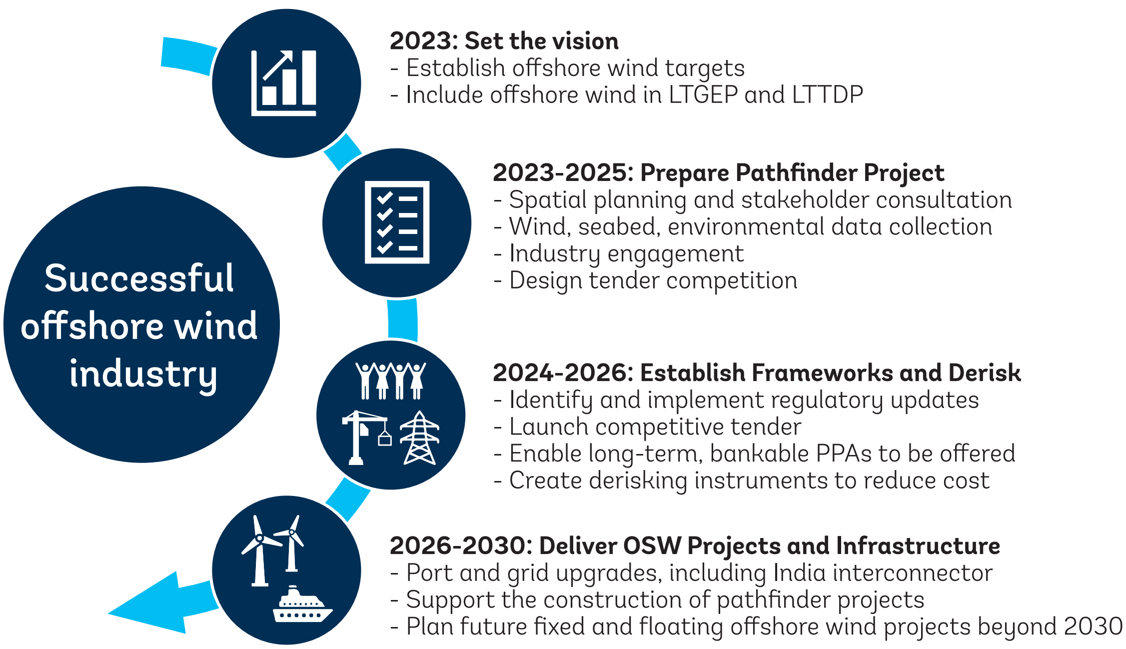
This roadmap identifies two large areas in the Gulf of Mannar that could be suitable for Sri Lanka's first offshore wind project(s). These two areas, which are close to Mannar Island and Puttalam, are shown in Figure ES.1. Both have shallow waters suitable for fixed foundation turbines and moderate wind speeds, averaging 8-9m/s.

To progress with this approach the Government would carry out the technical and regulatory activities shown in the first two area and site selection phases of Figure ES.3, to better understand the two potential areas and the regulatory changes that would be required to run a tender to award a project and power offtake agreement. Subsequently, in the site investigation, design, and permitting phase, Government agencies would need to conduct site surveys, feasibility studies, and tender design, as well as implement the necessary regulatory changes and initiatives needed to reduce the cost of financing for projects. Development partner or donor funding is likely to be required to help fund these activities.

RECOMMENDED ACTIONS

From the analysis and findings of this roadmap, we recommend 22 actions that are required to deliver the high growth scenario. Each of these recommendations is described in more detail in section 6 and evidence is provided in the Supporting Information found within sections 7 through 16 of the roadmap.

FIGURE ES.4: PRIORITY THEMES TO CREATE A SUCCESSFUL OFFSHORE WIND INDUSTRY.



The following points summarize the roadmap's 22 recommended actions.

Vision and Volume Targets

1. **Sri Lankan Sustainable Energy Authority (SLSEA) and Ceylon Electricity Board (CEB) should integrate offshore wind into the long-term generation expansion plan (LTGEP).** A holistic plan, supported by energy system modeling should consider the characteristics of offshore wind and its potential contribution to the country's decarbonization goals.
2. **SLSEA should establish a long-term vision for offshore wind including installation targets.** Including both shorter (i.e., 2030) and longer (i.e., 2050) targets helps investors to plan and gives confidence in the market opportunity. The vision should be informed by the LTGEP and economic analysis. Longer-term opportunities such as floating wind and green hydrogen should also be included in the vision.
3. **One or two 500MW pathfinder project(s) should be considered by SLSEA.** This capacity could be commissioned around 2030 and would help to overcome barriers and risks for future capacity additions, enabling subsequent cost reductions.

Regulatory and Policy Framework

4. **SLSEA in collaboration with other authorities such as Petroleum Development Authority of Sri Lanka (PDASL) and Marine Environmental Protection Authority (MEPA), should lead integrated spatial planning to identify and assess the preferred locations for future offshore wind projects.** The spatial planning should include stakeholder engagement and strategic baseline studies to ensure well informed site selection. This work can be supported by subsequent technical assistance from development partners.
5. **Sri Lanka should follow a government-led approach to planning and procuring the pathfinder project(s).** The SLSEA should plan this approach, discuss it with industry and other stakeholders, then publish it in the Sri Lanka Gazette. The process should be competitive, fair, and transparent, taking lessons from international experiences and incorporating them with local norms.
6. **SLSEA should carry out a regulatory gap analysis and identify any required amendments or new regulations to deliver the government-led procurement model.** Many elements of the framework can be adjusted to suit the requirements of offshore wind but others, such as the provision of seabed leases/concessions, may require new legislation.
7. **The Central Environmental Authority (CEA), in collaboration with SLSEA, should develop and publish detailed guidance on the permitting process.** This should include a list of all the permits, authorities, and timelines to be considered. This should also include the important environmental and social impact assessment (ESIA) process following good international industry practice (GIIP).

Financial and Economic

8. **SLSEA, with support from development partners, should investigate the use of derisking mechanisms, including guarantees, and opportunities to mobilize low-cost concessional finance.** The objective is to ensure the pathfinder project(s) risk is sufficiently mitigated to encourage investors and to reduce the cost of financing. This will help to reduce the cost of electricity and ensure the participation of competent, experienced developers, which will increase the chance of successful delivery.
9. **The CEB should establish a long-term, bankable, power purchase agreement (PPA).** This should take into account the specificities of offshore wind, fairly allocating risk between off-taker and developer, and ideally addressing exchange rate risk, repatriation of profits, and curtailment payments. The PPA must be considered bankable for projects to obtain debt financing.
10. **SLSEA and CEB should also consider the feasibility and potential benefits of renewable energy support schemes.** This would include any additional mechanisms needed to reduce the PPA price to an acceptable, affordable level.

Health and Safety (H&S)

11. **The Government should introduce H&S requirements in alignment with industry best-practice standards.** Adopting international standards with a long track record ensures safe procedures during installation and operation.

Grid and Port Infrastructure

12. **The Sri Lanka Ports Authority (SLPA) should assess port requirements and options for upgrading ports to support the installation of the pathfinder and subsequent projects.** This should consider the feasibility and merits for upgrading Sri Lanka's ports and whether there are more economical options.
13. **Assuming a local port should be upgraded, SLPA should undertake works to improve the capabilities of the port of Colombo and/or Hambantota.** The works should be strategic, considering opportunities to supply/service projects being developed in India, as well as domestically.
14. **SLPA should assess and upgrade smaller local ports to use in the O&M phase** in order to enhance local job creation, as well as ensure a reliable, safe, and lasting operation of the wind farms.
15. **CEB should include offshore wind in the next iteration of the long-term transmission development plan (LTTDP).** This should be based on the LTGEP, and the targets and timelines set by SLSEA.
16. **CEB should clarify which entity is responsible for constructing and operating the export system between an offshore wind farm and the onshore transmission grid.** It is recommended that this should be the responsibility of the developer, though CEB could be best placed to lead the onshore work.
17. **CEB should construct strategic transmission reinforcements. Given the scale and long development times of offshore wind projects, these sizable reinforcements should be planned and implemented well in advance of projects being commissioned.** They can be delivered strategically to avoid a less efficient project by project approach.
18. **The Ministry of Power and CEB should continue to explore the electrical interconnection link with India.** This could enable the partial or full sale of offshore wind generated power to consumers or markets in the region, as well as helping to balance the local grid and facilitate the integration of variable renewable energy.
19. **As part of a long-term decarbonization plan, SLSEA and PDASL should explore the potential to produce green hydrogen and ammonia.** It is unlikely to be economically viable in the shorter term but, in the absence of an interconnector with India, this could become a critical part of the Sri Lankan energy system. Alternatively, cheaper sources of electricity could be used to produce green hydrogen, and offshore wind be used to supply the grid.

Supply Chain

20. **SLSEA and the Sri Lanka Ports Authority (SLPA) should consider the merits of incentives to support industry growth and local supply chain capability.** This could, for example, include tax exemptions/reductions, availability of reduced rate land/property within port areas, or access to lower-cost finance.
21. **SLSEA and relevant Government agencies should map local supply chain capabilities.** This should identify local firms with any capability or likely future capability to supply or service offshore wind projects.
22. **SLSEA should consider establishing strategic regional partnerships with other offshore wind markets.** Suppliers in India, China, and Vietnam, for example, could be an alternative to overcome domestic supply chain constraints and to both draw on regional skills and help develop them domestically.

1 INTRODUCTION

The World Bank Group (WBG) launched a new global initiative on offshore wind in March 2019. The Offshore Wind Development Program is led by the Energy Sector Management Assistance Program (ESMAP) in close partnership with the IFC[2]. The Program's objective is to support the inclusion of offshore wind into the energy sector policies and strategies of emerging market countries and support the preparatory work needed to build a pipeline of bankable projects.

In this context, Sri Lanka has a significant potential for offshore wind. In recent analysis by the World Bank Group [1], Sri Lanka's offshore wind technical potential[3] was estimated at 92GW, comprising 55GW from fixed offshore wind and 37GW from floating offshore wind (i.e., in water depths >50m). Sites in the northwest of the country's waters, such as the Gulf of Mannar and Palk Bay appear to have strong wind resource combined with relatively shallow waters making it potentially suitable for deployment of fixed offshore wind. The southeast waters also present good wind conditions, but quickly turn into deeper waters implying floating offshore wind solutions.

This roadmap was commissioned by WBG following a request from the Government of Sri Lanka for assistance on assessing the country's offshore wind opportunity. The work was funded by ESMAP and PROBLUE. It has benefited from a wide range of input received from stakeholders representing industry, governmental, and non-governmental organizations.

The objective of this roadmap is to provide strategic analysis and advice on the role that offshore wind could play in Sri Lanka's future energy mix, analysis on the key opportunities and challenges, and recommendations on next steps in terms of policy formulation, planning, and developing bankable projects. The assignment shall inform the WBG advice to the Government of Sri Lanka and the Government's consideration of policy and investment options for offshore wind. The international consulting firm COWI was commissioned to lead the roadmap, working closely with the WBG team, as well as the Lanka Hydraulic Institute, EML Consultants, and the Biodiversity Consultancy.

This roadmap has been prepared based on desk studies and stakeholder consultations. Meetings have been held with relevant authorities in Sri Lanka, as well as other important stakeholders. Furthermore, four stakeholder consultations obtained feedback from the following stakeholder groups:

- **Government stakeholders**: Ministry of Power and Renewable Energy, Sri Lankan Sustainable Energy Authority (SLSEA), Ceylon Electricity Board (CEB)
- **Private sector stakeholders**, including project developers: Wind Force Ltd, LTL Holdings Ltd, Senok Wind Power Pvt. Ltd. Lanka Transformers, Celex Renewables, Chamber of Commerce (committee on RE/energy)

2 IFC — International Finance Corporation is an international financial institution that offers investment to encourage private-sector development in less developed countries. IFC is member of the World Bank Group.

3 The technical potential is the achievable capacity, generation, and suitable area for offshore wind technology given seabed conditions and wind resource only, not taking into consideration environmental and social constraints. Note, this report assumes that fixed offshore wind is more likely to be economically viable in water depths less than 50, however, as technology has evolved, it is technically feasible to install fixed foundations in depths of up to 70m.

- **Domestic Financial Institutions**: NDB Bank, DFCC Bank PLC, Commercial Bank of Ceylon PLC
- **International Financial Institutions**: IFC, Asian Development Bank, Japan International Cooperation Agency (JICA)

Depending on the extent to which any roadmap recommendations are implemented, and market conditions, there are a range of growth outcomes possible for the offshore wind industry. As a result, and to illustrate possible development paths for offshore wind in Sri Lanka, two hypothetical deployment scenarios were developed — a low and a high growth scenario. The scenarios were developed based on feedback from stakeholders, assessments of the state of offshore development today, statements on the political aspirations of Sri Lanka, and an assessment of the overall potential for offshore wind in the country. Note that these two growth scenarios are covered in detail in section 3.2.

The structure of this report is comprised of a main body (Chapters 2-6), which summarize the key findings and conclusions of this report, as well as presenting the roadmap. Chapters 7-15 present a more detailed analysis of the themes of this report.

2 BACKGROUND

Sri Lanka has a gross domestic product (GDP) per capita of US$3,852 (2019) and a total population of 21.8 million. Since the end of the three-decade civil war in 2009, Sri Lanka has begun focusing on long-term strategic and structural development challenges.

The country has traditionally relied on the agricultural sector as a major source of economic output. However, today the share of agriculture in Sri Lanka's GDP is only around eight percent. Industry contributes with approximately 26 percent and the service sector is now by far the dominant contributor to GDP with about 60 percent.

The overall economic picture in Sri Lanka has been impacted severely by the COVID-19 pandemic, with economic growth sharply contracting in 2020 [2]. The impact has left Sri Lanka with output drops in many sectors, and the government has acted to support flagging sectors. However, recent projections by The World Bank and Asian Development Bank foresee a growth rate in 2021 of 3-4 percent.

With a growing economy and continued electrification of the country and various sectors, electricity demand is expected to grow significantly. However, it will be challenging for the Sri Lankan energy sector to meet the growing demand with affordable and reliable electricity. The share of fossil fuels in the power generation mix has been increasing, and efforts to shift to clean energy have been hampered by a lack of capacity, incentives, and investments to develop large-scale renewable energy projects and associated transmission facilities.

Sri Lanka has, though, made significant effort in developing green and renewable energy in recent years, with a notable capacity addition in onshore wind comprising inter alia the 100MW Mannar Onshore Wind Farm. However, with the ambitious target of obtaining 70 percent of electricity generation via renewable energy sources by 2030 and a full 100 percent renewable energy generation by 2050, offshore wind becomes a relevant and important technology to consider developing.

2.1 CURRENT ELECTRICITY SECTOR

In 2021, the total electricity net generation amounted to 16,716GWh [3]. This was supplied by a total installed capacity of 4,186MW. The typical maximum power demand is approximately 2,800MW, often occurring between March to May.

Electricity generation in Sri Lanka is dominated by oil and coal-fired thermal power generation (49 percent of supply) and hydro power (43 percent, comprising both large- and mini-scale hydro). The remaining eight percent of generation was supplied by wind, solar, and other RE capacity. A summary of this generation mix is shown in Figure 2.1 and statistics for 2021 are provided in Table 2.1.

Sri Lanka does not currently have any gas-fired power generation, however the country's first Liquid Natural Gas (LNG) combined cycle plant is under construction at Kerawalapitiya and will have a total capacity of 300MW. Gas-fired generation capacity is expected to increase further — see section 2.2.

Over three quarters of power generation capacity is owned by the Ceylon Electricity Board (CEB), with the remaining 24 percent of the country's generation owned by independent power producers (IPPs). Typically, these IPPs are domestic firms with relatively small-scale (<100MW) projects.

Hydro generation varies throughout the year depending on the monsoon season and the availability of water in the reservoirs. During the dry season (January to April), water levels in the reservoirs tend to be low, leading to reduced hydro power generation. In contrast, during the monsoon season (May to October), high rainfall raises the water levels in the reservoirs and increases hydro generation. Typically, thermal generation increases during the dry season to counter the reduced hydro output.

The country's reliance on hydro and thermal power generation increases the risk of disruption due to the availability of water (rainfall) and fuel. In early 2022, the increased demand for fossil fuels during the dry season contributed to the economic crisis (see section 2.4) and insufficient foreign capital was available to import the fuel needed to meet demand; as a result, the grid was unable to supply its customers and blackouts occurred. Furthermore, the recent high prices of fossil fuels substantially increased the cost of generation, and Sri Lanka is exposed to future price volatility.

The Sri Lankan electricity market is currently a single buyer model with CEB as the single, state-owned, integrated utility. There is no electricity spot market or renewable support schemes for projects of the typical size of offshore wind farms. The government is currently planning a major sector reform which may start introducing steps towards a wholesale market, but the details are not yet known. Future renewable energy schemes are likely to be a major determinant of offshore wind development, and the suitability of these schemes should be considered in the next stages of offshore wind development following on from this roadmap.

FIGURE 2.1: SRI LANKA POWER GENERATION IN 2021, SHOWING PERCENTAGE OF TOTAL ELECTRICITY GENERATED[3].

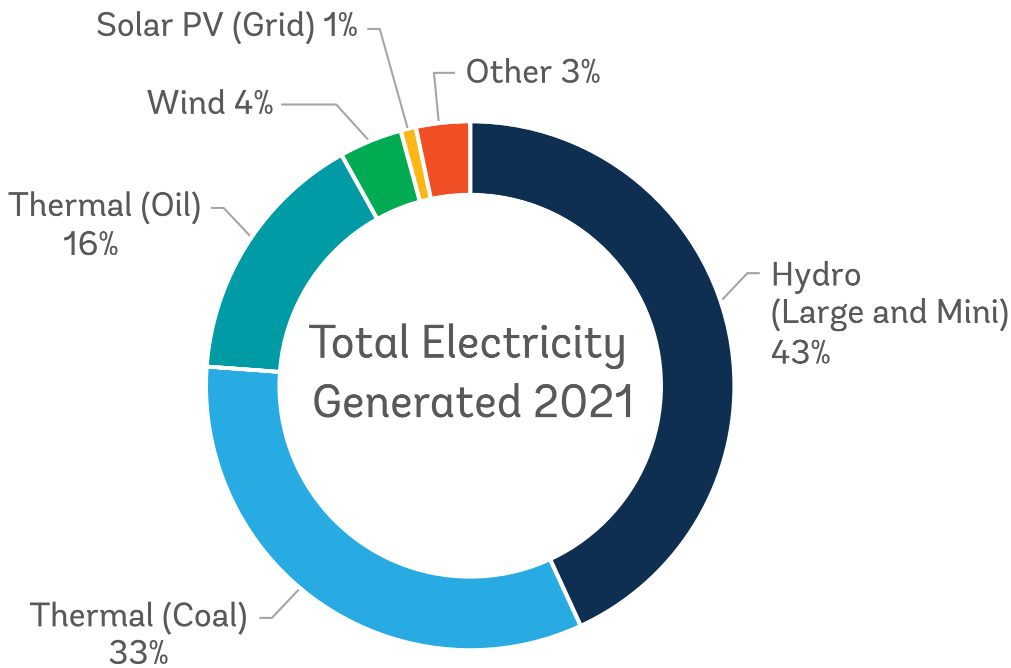


TABLE 2.1: POWER GENERATION STATISTICS FOR 2021[3].

Ownership	Type	MW	GWh	Capacity Percentage of Total	Generation Percentage of Total
CEB	Major Hydro	1,383	5,640	33%	34%
	Thermal (Oil)	654	1,231	16%	7%
	Thermal (Coal)	900	5,519	22%	33%
	Wind	104	318	2%	2%
	TOTAL	**3,041**	**12,708**		
IPP	Thermal (Oil)	433	1,400	10%	8%
	Mini Hydro	414	1,568	10%	9%
	Wind	148	327	4%	2%
	Other RE	50	163	1%	1%
	Grid Solar PV	100	156	2%	1%
	Rooftop Solar PV	N/A	389	N/A	2%
	TOTAL	**1,145**	**4,003**		
	Combined Total	**4,186**	**16,711**		

3 The technical potential is the achievable capacity, generation, and suitable area for offshore wind technology given seabed conditions and wind resource only, not taking into consideration environmental and social constraints. Note, this report assumes that fixed offshore wind is more likely to be economically viable in water depths less than 50, however, as technology has evolved, it is technically feasible to install fixed foundations in depths of up to 70m.

2.2 FUTURE ELECTRICITY DEMAND AND GENERATION

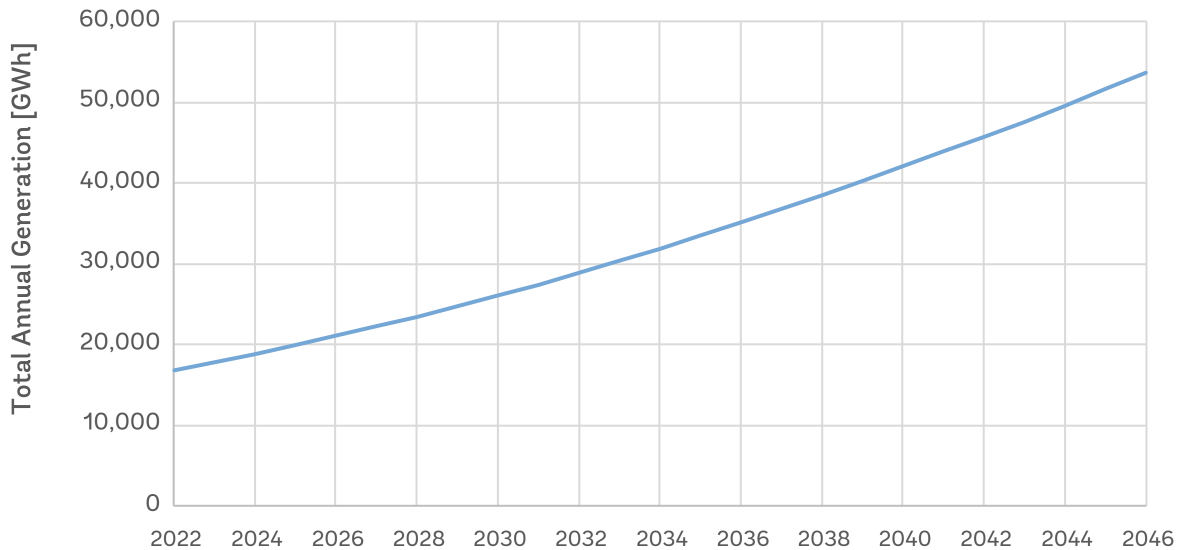
2.2.1 Future Demand

Demand for electricity in the country has been growing at an average rate of about 4.4 percent per annum during the last fifteen years [4], though it contracted during 2020 due to the COVID-19 pandemic.

Annual power demand is expected to increase from 16,741GWh in 2022, to 53,703GWh by 2046. This represents a demand increase of over 220 percent in that period, and a 25-year average annual growth rate of five percent [4]. Peak demand is expected to exceed 9GW by 2046. While grid connectivity has reached most parts of the country, the growth is a result of increased industrial, commercial, and consumer demand.

The "base case" forecast electricity demand between 2022 and 2046 is shown in Figure 2.2.

FIGURE 2.2: SRI LANKA'S BASE DEMAND FORECAST FOR ELECTRICITY BETWEEN 2022 AND 2046 [4].



Source: CEB

2.2.2 Renewable Energy Targets

In pursuance of increased adoption of renewable energy, Sri Lanka has set a target to use only renewable energy for electricity generation by 2050. The target shall be obtained by a phased approach with 70 percent renewable energy in electricity generation by 2030, and 'carbon neutrality' in electricity generation by 2050. This pledge is underlined in Sri Lanka's recently (2021) Updated Nationally Determined Contributions (NDCs) under the UNFCCC framework [5] where the two renewable energy targets for electricity generation is explicitly confirmed. Additionally, the NDC states that Sri Lanka commits to no capacity addition of coal power plants.

Sri Lanka already has a good share of renewable energy in the electricity generation mix. Reaching 70 percent by 2030, however, is a huge task and will require significant new renewable energy capacity.

2.2.3 Future Generation

The CEB long term generation expansion plan (LTGEP) 2022-2041 [4] considers the future generation mix required to meet this demand under four policy scenarios, including a base case and +50 percent renewable electricity generation by 2030. The LTGEP was approved in mid-2021, before the country's NDCs were updated and therefore does not consider the commitment to avoid building new coal-fired generation. A new LTGEP plan[4] is being prepared for the period 2023-2042 [6]. This will align the plan with the Government's target of 70 percent renewable energy by 2030 and commitment for no new coal generation. The draft plan notes that the large potential for offshore wind power development in northwestern and southeastern regions have been identified by initial assessments in World Bank Group studies. The new LTGEP will also include a larger contribution of low-carbon energy (to replace planned coal and other thermal generation) and therefore could include additional large-scale variable renewable energy, such as offshore wind.

The 2022-2041 LTGEP foresees the use of fossil fuel in combination with renewable energy-based power generation options to meet the increasing electricity demand. Under the 'current policy' scenario, the plan forecasts over 6GW of new fossil fuel capacity[5] to be added by 2041. The scenarios plan for 600 to 2,400MW of new coal generation by 2041 with a typical plant factor of 80-85 percent. This planned new coal capacity will need to be replaced by low-carbon energy sources in the next revision of the LTGEP.

The plan also forecasts over 6.5GW of variable renewable energy additions by 2041 and states that up to 1,100MW of wind could be operational by the end of 2030, with approximately 100MW being added annually thereafter, leading to +2,000MW of wind by 2040. Note that, at the time of writing, the draft LTGEP for 2023-2042, anticipates a total installed capacity of +3,200MW of wind by 2040; a substantial increase on the previous LTGEP version and reflecting Sri Lanka's recent policy commitments.

Sri Lanka has significant potential for solar, onshore wind, and biomass, and, when coupled with the existing hydro generation, could be sufficient to supply Sri Lanka's future decarbonized energy system. For example, SLSEA's Renewable Energy Resource Development Plan 2021-2026 [7] estimates Sri Lanka's renewable energy resources and identifies land areas for around 10GW of onshore wind, 30GW of solar PV, 900MW of floating solar PV, and 800MW of biomass potential. It also prioritizes land for around 1GW of large-scale wind and solar PV projects to be delivered in this 5-year period.

Progress in developing large-scale renewable electricity generation, however, has been slow. Agriculture is a critical part of Sri Lanka's economy, so land is a precious resource; this could hamper the buildout of large onshore renewable generation. Therefore, it may not be possible to meet the 2030 renewable energy targets with onshore resources alone, and offshore wind could help to add sizable capacity with a single project.

4 The draft LTGEP (2023-2042) was made publicly available for stakeholder comments in October 2022 by the Public Utilities Commission of Sri Lanka.

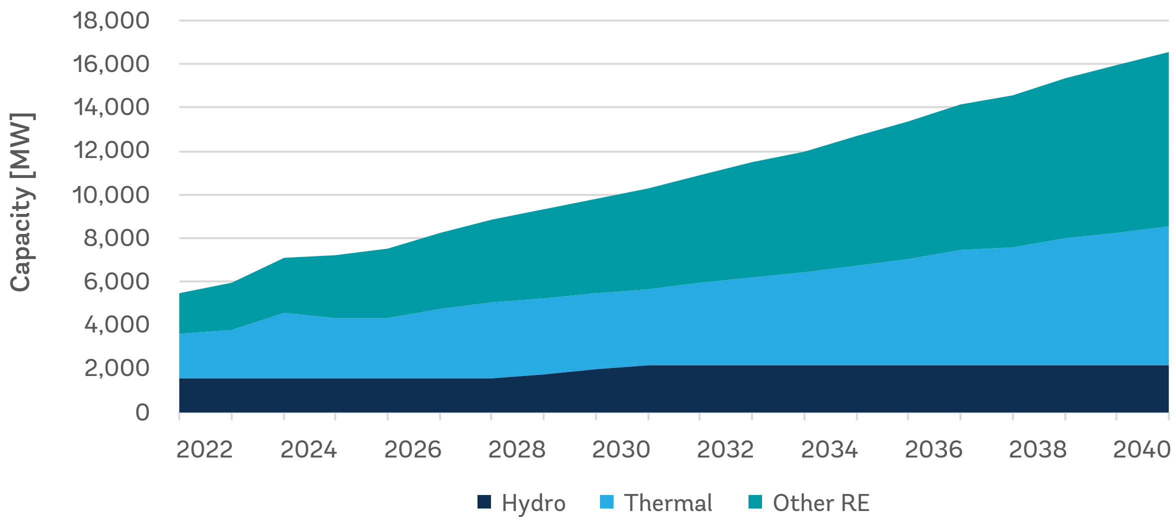
5 Comprising; Gas (1,230MW), Coal (2,400MW), Combined Cycle (1,500MW), and IC engines (900MW).

Sri Lanka has some of the highest electricity costs in Asia. As all fuel is currently imported, the country is exposed to future fuel price variability. The LTGEP assumes the following future costs for new thermal generation:

- Natural Gas (combined cycle), with a project size of 300-400MW: 9 to 12 US Cent/kWh
- Coal, with a project size of 300-600MW: 7 to 10 US Cent/kWh

Costs for variable renewable energy, such as wind and solar, are also assumed to be comparatively high (typically 7 to 10 US Cent/kWh), but this assumes relatively small-scale projects of around 10MW.

FIGURE 2.3: BREAKDOWN OF TOTAL INSTALLED CAPACITY BETWEEN 2022 AND 2041, AS PER THE LTGEP 2022-2041 [4].



Source: CEB

2.2.4 Interconnector with India

An electrical interconnector between Sri Lanka and India has been considered many times in the past, but a project has not yet been taken forward. Government-to-government dialogue on the interconnector has recently resumed and a 500MW High Voltage Direct Current (HVDC) link was analysed in one of CEB's LTGEP scenarios. Work is ongoing to assess the technical, commercial, and economic feasibility of the interconnector, but it is expected to be mutually beneficial for both countries; with Sri Lanka having an additional source of power to aid system balancing, and India benefitting from additional supply of renewable electricity at times where not all generated power is required in Sri Lanka.

Power from large-scale offshore wind, or other renewable energy capacity, could be partially or entirely exported to India (or other South Asian consumers) via the interconnector. This could enable the buildout of more renewable electricity generation than required domestically and would provide a new source of foreign revenue for Sri Lanka.

Further information on the interconnector is provided in section 11.3.3.

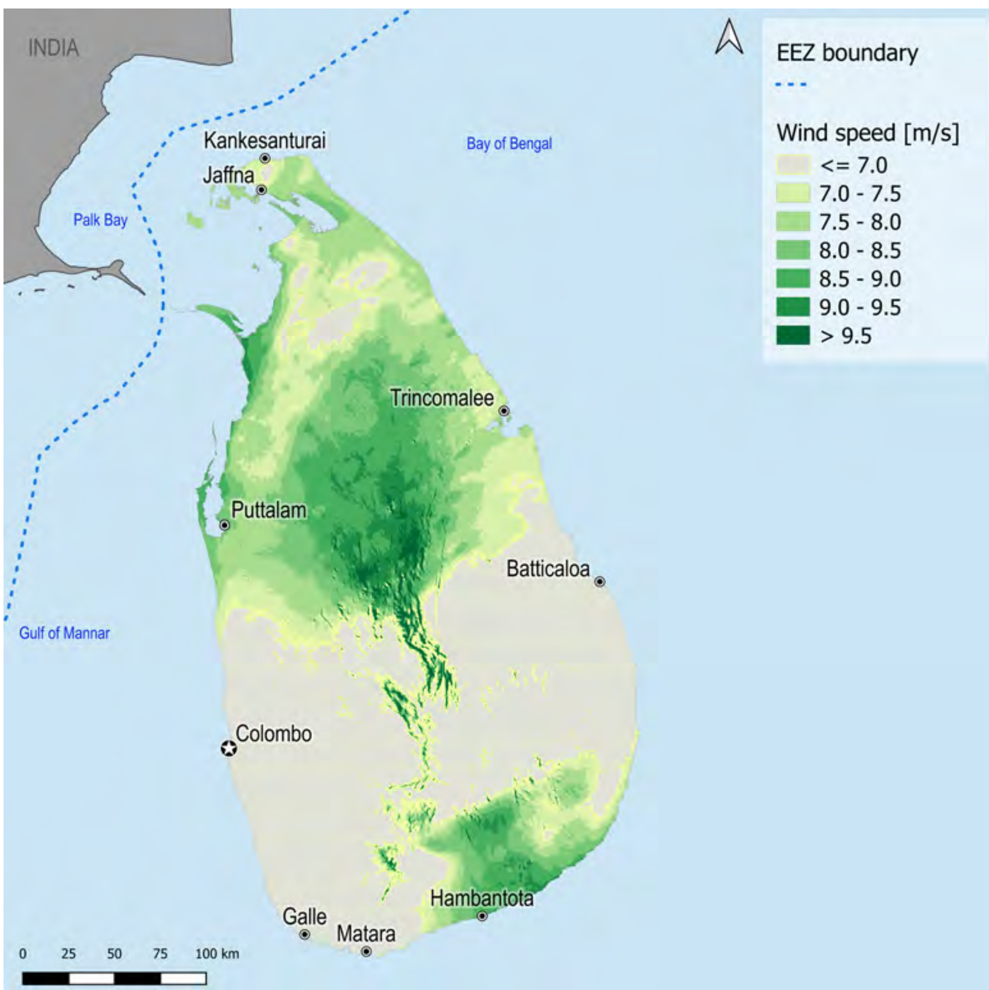
2.3 ONSHORE WIND IN SRI LANKA

Sri Lanka has a good resource potential for onshore wind power development, with many areas having annual average wind speeds of greater than 7m per second[6], as demonstrated by Figure 2.4 extracted from the Global Wind Atlas.

Sri Lanka experiences two monsoon seasons: the southwest monsoon season from May to September and the northeast monsoon season from December to February. Wind speeds are typically higher during the northeast monsoon season. During the inter-monsoon seasons (October to November and March to April), the wind speed tends to be lower and more variable, resulting in lower power generation potential.

The total estimated onshore wind potential based on the wind resource and constraints was estimated at 10GW by SLSEA [7]. However, because of unknown constraints and economic feasibility, the realizable potential is likely to be much lower, and some sources [8] estimate it could be as low as 1GW. Consequently, this makes Sri Lanka's offshore wind power potential even more relevant as a renewable energy source.

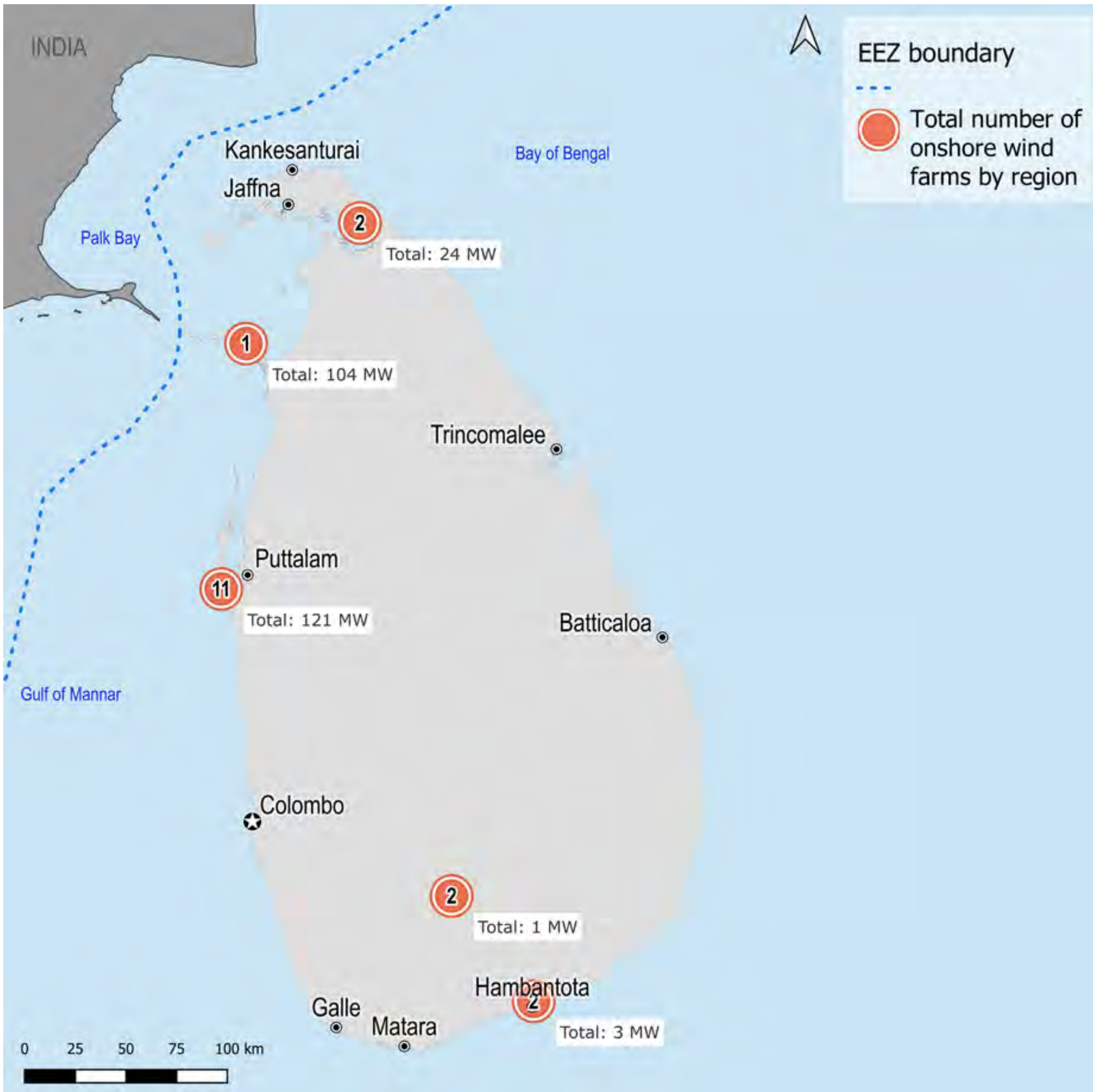
FIGURE 2.4: ANNUAL AVERAGE ONSHORE WIND SPEEDS AT 100M HEIGHT [9].



6 This is a typical benchmark for 'good' onshore wind resources. Capacity deployed in areas with average wind speeds of 6 to 7m/s may also be economically viable.

The installed operational onshore wind capacity is currently 252MW distributed between 18 projects — see Figure 2.5. A major part of the capacity is located just north of Colombo in Puttalam area. The largest onshore wind farm to date with a capacity of 104MW is located at Mannar in the northwest of the country. Some of the country's more energetic sites are located far inland but, due to grid and transportation challenges, development has been closer to the coasts.

FIGURE 2.5: LOCATION, BY REGION, OF ONSHORE WIND FARMS IN SRI LANKA.



Source: www.thewindpower.net

2.4 ECONOMIC CLIMATE

The economic climate in Sri Lanka is strained due to high levels of debt as a result of poor fiscal and monetary policy in the past several years. Subsequently, it is expected that Sri Lanka's real GDP will have dropped by 9.2 percent at the end of 2022 and may further contract by 4.2 percent in 2023 [10]. After the previous president resigned in 2022 following demonstrations, political and economic uncertainties have continued to persist. An IMF support package is expected to be forthcoming in 2023, and the government is planning a number of reforms, including a significant power sector and tariff reforms.

Sri Lanka has been highly dependent on importing fossil fuels to meet energy demand. This, combined with large imports in other sectors, created a large trade deficit. In 2022, CEB estimated [4] that Sri Lanka spent around US$570 million per year on fossil fuel imports for power generation (including on diesel, fuel oil, naphtha, and coal). By 2040, the annual cost of fossil fuel imports[7] is expected to rise to around US$1.5 billion per year, further exacerbating the trade imbalance.

In 2022, the large reduction in foreign income from tourism due to the COVID-19 pandemic, combined with the rapid rise in fossil fuel prices due to the war in Ukraine, led to the country having insufficient foreign currency (primarily US$) and defaulting on its debts in May 2022. Sri Lanka was unable to make payments to import fuels which caused a fuel crisis that eventually led to the widespread public demonstrations [11].

A long-term solution to break the dependency of importing fossil fuels could be large-scale deployment of renewables, such as solar, onshore wind, and offshore wind. This would reduce the country's fuel import payments and help to conserve valuable foreign currency. The large-scale deployment of renewable energy is also essential for the country to meet its targets of 70 percent renewable electricity by 2030 and 100 percent in 2050. As discussed in this Roadmap, Sri Lanka has significant potential for offshore wind and it could make a valuable contribution to the renewable energy mix, alongside hydro, solar, and onshore wind.

Establishing an offshore wind industry in Sri Lanka and developing a supply chain would benefit the country in several environmental, economic, and socio-economic areas. It has shown to benefit job creation and access to clean and affordable energy without the need to import large amounts of fossil fuels. At large, Sri Lanka would benefit from reduced emissions, energy independence, and foreign direct investment (FDI).

The time to develop an offshore wind farm (OWF) is long — typically seven to ten years — which means that, to achieve the ambitious goals, progress needs to start today. The government will need to proactively attract developers by creating incentives which derisk and ease the process for permitting and procurement routes. These should be considered as part of the scoping of the overall support package the government will need to offer developers.

The economic and political situation in Sri Lanka remains challenging in the short term and requires consistent and sustained efforts from leaders. However, certain actions could improve specific parts of the economy and benefit the country. Establishing an offshore wind market could be such an action.

7 By 2040, diesel, oil, and naphtha will have been phased out of the power sector and replaced with Liquid Natural Gas (LNG).

2.5 OFFSHORE HYDROCARBON EXPLORATION

The Petroleum Development Authority of Sri Lanka (PDASL) under the Ministry of Power and Energy, is responsible for regulating the exploration and production of oil and gas. Historically, offshore exploration has occurred in the Cauvery Basin around Mannar Island, and in the Mannar Basin, further offshore of Puttalam/Kalpitiya peninsular. Small discoveries were made in the Mannar Basin but no commercial extraction has occurred. PDASL is preparing a new regulatory framework [12] to renew exploration efforts as it believes Sri Lanka has substantial offshore hydrocarbon reserves.

There may be some overlapping areas between offshore hydrocarbon exploration (and future extraction) and areas feasible for offshore wind development, particularly in the Gulf of Mannar. This could cause some challenges in managing the shared use of marine space, but could also offer opportunities for collaboration and potentially co-location of offshore energy activities. It will be important to understand related experiences from other countries, for example the Scottish Innovation and Targeted Oil and Gas (INTOG) offshore wind leasing round, and apply them to the Sri Lankan context.

SLSEA and PDASL should closely coordinate to help ensure efficient use of Sri Lanka's offshore energy resources, and to avoid duplication of efforts. Given PDASL's experience with the offshore environment and stakeholders, it would be beneficial for the agency to actively support offshore wind development activities.

2.6 OFFSHORE WIND IN INDIA

Offshore wind is a global industry, and it is important for new markets to consider their position and opportunities within the wider global and regional markets. India has offshore wind resources in the states of Gujarat and Tamil Nadu. Its Ministry of New and Renewable Energy (MNRE) established a target of 30GW by 2030 [13] and has published strategic papers describing how that will be achieved [14]. It is expected that, in 2023, MNRE will run India's first competitive allocation of seabed for +4GW of offshore wind capacity in Tamil Nadu's waters. A preliminary spatial plan for Tamil Nadu, carried out by the Centre of Excellence for Offshore Wind and Renewable Energy, [15] identified at least 3,600km^2 across 14 priority offshore wind potential areas; this is equivalent to between 10-25GW of potential, depending on the actual site characteristics.

India's offshore wind development will occur near Sri Lanka. The high priority sites in Tamil Nadu are off the southern tip of India, and around 200-300km from Colombo. One of the broader areas of potential (close to Adam's Bridge) has a boundary with Sri Lanka's EEZ. The proximity of these sites means that Sri Lankan ports and supply chain could service Indian projects. The opposite is also true; capable Indian ports such as Tuticorin [16] and the local supply chain that is likely to develop around it, will have an opportunity to supply to future Sri Lankan projects.

Cooperation between Sri Lanka and India on the development of offshore wind in this region could be mutually beneficial. A larger overall offshore wind capacity provides the industry and investors with a larger project pipeline and commercial opportunities. This could help to reduce the overall cost of energy for projects in Tamil Nadu and Sri Lankan waters.

While India has ambitious targets for offshore wind, the size of its overall practical resource potential is small in comparison to its future power demands and offshore wind will only make a relatively modest contribution. India will need to source power from many different resources as well as other countries. This provides Sri Lanka with an opportunity to supply India with excess electricity, if it is able to develop sufficient large-scale renewable energy generation and an interconnector with India (see section 11.3.3).

2.7 DRIVERS FOR ESTABLISHING OFFSHORE WIND

As the global offshore wind industry has matured over the last 20 years, experience from European early adopters shows that each country has charted its own path and that there are multiple ways to establish a successful offshore wind industry (see Figure 3.4 in [17]). The paths that these countries have taken are influenced by the existing regulatory frameworks, political preferences, and characteristics of the available wind resource. What they have in common is that these countries have been able to find their own ways to fulfill the key requirements for first establishing and then growing an offshore wind industry.

Though Sri Lanka is building experience developing onshore wind, there are important differences between onshore and offshore wind. In addition to the challenges of marine planning and construction, the principal difference lies in the investment size of offshore wind farms. In Europe, the average wind farm size has been continually increasing, as larger sizes create economies of scale and reduce the LCOE. In 2020, the average European wind farm size was 788MW and project developers in new markets are typically looking for wind farm sizes of at least 500MW [18]. In this size range, capital expenditures for a wind farm are typically US$1-2 billion, with total development expenses usually between US$50-100 million.

Due to the large investments required and the long project development time, experience has shown that countries hoping to establish an offshore wind sector must pave the way in a few key areas. The World Bank Group's 2021 report "Key Factors for Successful Development of Offshore Wind in Emerging Markets" discusses in depth what is required to build up an offshore wind industry in emerging markets, from policy to frameworks and delivery [17].

This roadmap focuses on the application of selected factors in the Sri Lankan context:

- **Favorable natural site conditions** – does Sri Lanka have large areas with wind speeds above 7m/s? How much of these areas are socially and environmentally restricted? Based on the seabed characteristics, what is the potential for fixed vs. floating wind?
- **Grid and port infrastructure** – how much of Sri Lanka's port and grid infrastructure can be used for offshore wind? What kind of upgrades are expected to be necessary?
- **Supply chain** – how much capacity and experience do Sri Lankan companies have in offshore wind or related sectors? What are the incentives for wind farm developers to source within Sri Lanka?

- **Health and safety** – what must Sri Lanka do to ensure that the jobs provided by offshore wind are safe?
- **Permitting and regulatory framework** – how can the risk of project development be fairly allocated? Are permitting frameworks transparent and as simple as possible?
- **Financing and power purchase** – what are realistic costs for the short term? Is power offtake secure and bankable? How can Sri Lanka attract project developers in what is increasingly becoming a seller's market?

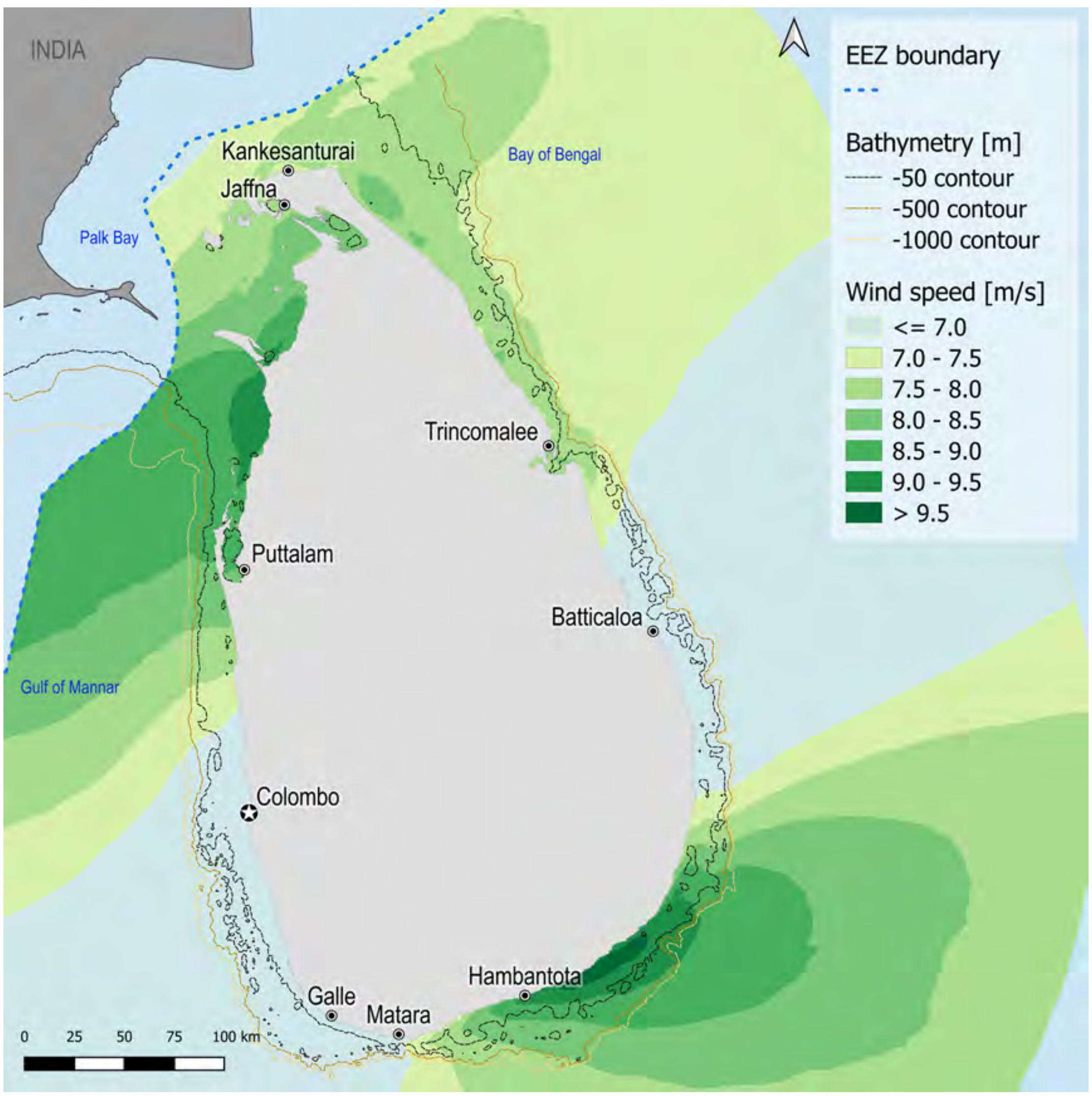
These factors are reflected in the structure of the key findings (Chapter 3) and the detailed analysis.

3 KEY FINDINGS

3.1 SUITABILITY ASSESSMENT OF OFFSHORE WIND AREAS

In a global context, Sri Lanka's offshore wind speeds are moderate with a relatively even distribution. There are small pockets of wind resources exceeding 9m/s (which can be categorized as 'high wind' sites) north of Puttalam and east of Matara and larger swaths in the range of 8-9m/s (which can be categorized as 'medium wind' sites), as shown in Figure 3.1.

FIGURE 3.1: AREAS WITH MEAN WIND SPEED HIGHER THAN 7.0M/S AT 150M BASED ON GLOBAL WIND ATLAS [19].



The bathymetry offshore Sri Lanka shows that relatively shallow waters (i.e., <50m) suitable for fixed foundations are found to the north between Sri Lanka and India, whereas areas of shallow waters are more limited in the south, implying a need for floating foundations.

The assessment of seabed and seismic conditions shows that, in general, there appear to be no major seabed obstacles or challenges for construction and operation of offshore wind farms. Earthquakes are not considered a major concern. However, development of sites close to shore must take into consideration tsunami incidents and especially the potential scour related to low amplitude tsunami waves.

Offshore wind must be developed sustainably and avoid causing large negative impacts on environmental and social (E&S) receptors. If projects are to benefit from lower-cost international financing and financing from concessional sources (such as climate funds), development needs to meet international lenders' requirements. These financiers typically require projects to meet E&S standards that align with Good International Industry Practice (GIIP). To conduct an initial, high-level assessment of Sri Lanka's technical and E&S constraints, this roadmap identifies the major sensitivities, using existing data, and maps them into two zones, depending on the level of constraint:

- **Exclusion zones** comprised of areas of the highest technical and E&S sensitivities and are considered as "no-go" areas to exclude from offshore wind site selection.
- **Restriction zones** are high risk areas requiring further assessment of technical and E&S risks through marine spatial planning (MSP), site selection, and/or environmental and social impact assessment (ESIA). While development may be possible in these zones, it is likely that substantial measures will be required to manage and mitigate adverse impacts.

Table 3.1 summarizes which constraints fall into each category. Further information on this analysis is provided in section 3.3 and the accompanying study on priority biodiversity values, in Appendix A.

TABLE 3.1: TECHNICAL, ENVIRONMENTAL, AND SOCIAL SENSITIVITIES WITHIN EXCLUSION AND RESTRICTION ZONES.

Exclusion Zones	Restriction Zones
Marine national parks	Ecologically or Biologically Significant Marine Areas (EBSA)
Nature reserves	Important Marine Mammal Areas (IMMA)
Sanctuaries	Habitat for Dugong
Key Biodiversity Areas (KBA) (incl. Important Bird Areas (IBA), Ramsar sites, and UNESCO-MAB Biosphere Reserve)	Highest density shipping areas*
Sea turtle nesting beaches	Subsea cables*
Seagrass beds, mangroves, and coral reefs	
Military exercise areas*	
Airport radar*	
Oil & gas operations*	

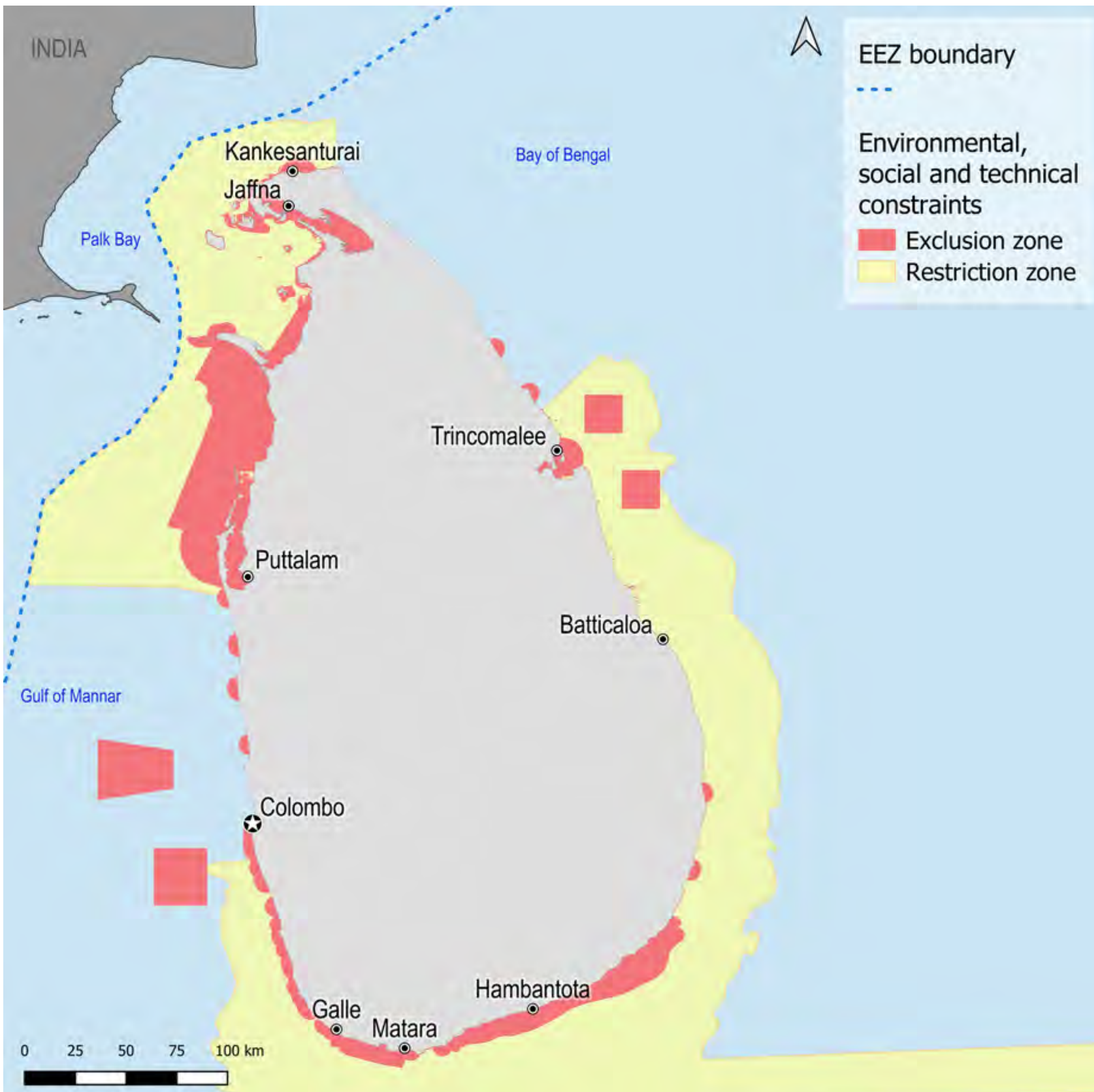
*Defined as a technical constraint/sensitivity, not E&S.

The spatial distribution of the combined exclusion and constraints are mapped in Figure 3.2. This shows that the majority of Sri Lanka's coastal waters contain some degree of significant environmental or social sensitivity. Exclusion zones are primarily found very close to shore in the southern and southwestern part of the country as well as in the northwest above Puttalam and in the Gulf of Mannar. Large restriction zones are located in Palk Strait and also cover the coast from Colombo to Trincomalee.

Some stretches of Sri Lanka's coast have fewer constraints and include the areas between Jaffna and Trincomalee as well as between Puttalam and Colombo. Although these areas have fewer exclusion and restriction zones, they may contain sensitivities that have not been identified in this initial assessment.

Particular E&S issues are likely to include marine mammals (especially blue whales and dugong), turtles, migratory birds (especially along the west coast), artisanal fisheries, and commercial shipping routes.

FIGURE 3.2: EXCLUSION AND RESTRICTION ZONES FOR TECHNICAL, ENVIRONMENTAL, AND SOCIAL SENSITIVITIES.



Source data: see section 3.3 and Appendix A

The potential offshore wind areas for Sri Lanka have been derived by combining the data sets on wind speed, technical constraints, E&S constraints, and bathymetry. Fixed foundation offshore wind farms are usually located within areas which meet the basic technical requirement — average wind speeds greater than 7m/s and water depth of 50m or less — avoid exclusion zones and, ideally, also avoid restriction zones.

Figure 3.3 shows large areas in the north of Sri Lanka from Jaffna to Trincomalee and areas to the south of Puttalam which meet these conditions. These areas also have deeper waters, further from shore, with few exclusion and restriction zones, and so appear to be suitable for floating wind projects.

Additional areas which are in restriction zones can be found from Jaffna southwest to Puttalam and in the south from Matara to Pottuvil.

FIGURE 3.3: COMBINED DATASETS ON TECHNICAL CONDITIONS AND CONSTRAINTS, USED TO IDENTIFY AREAS SUITABLE FOR OFFSHORE WIND.

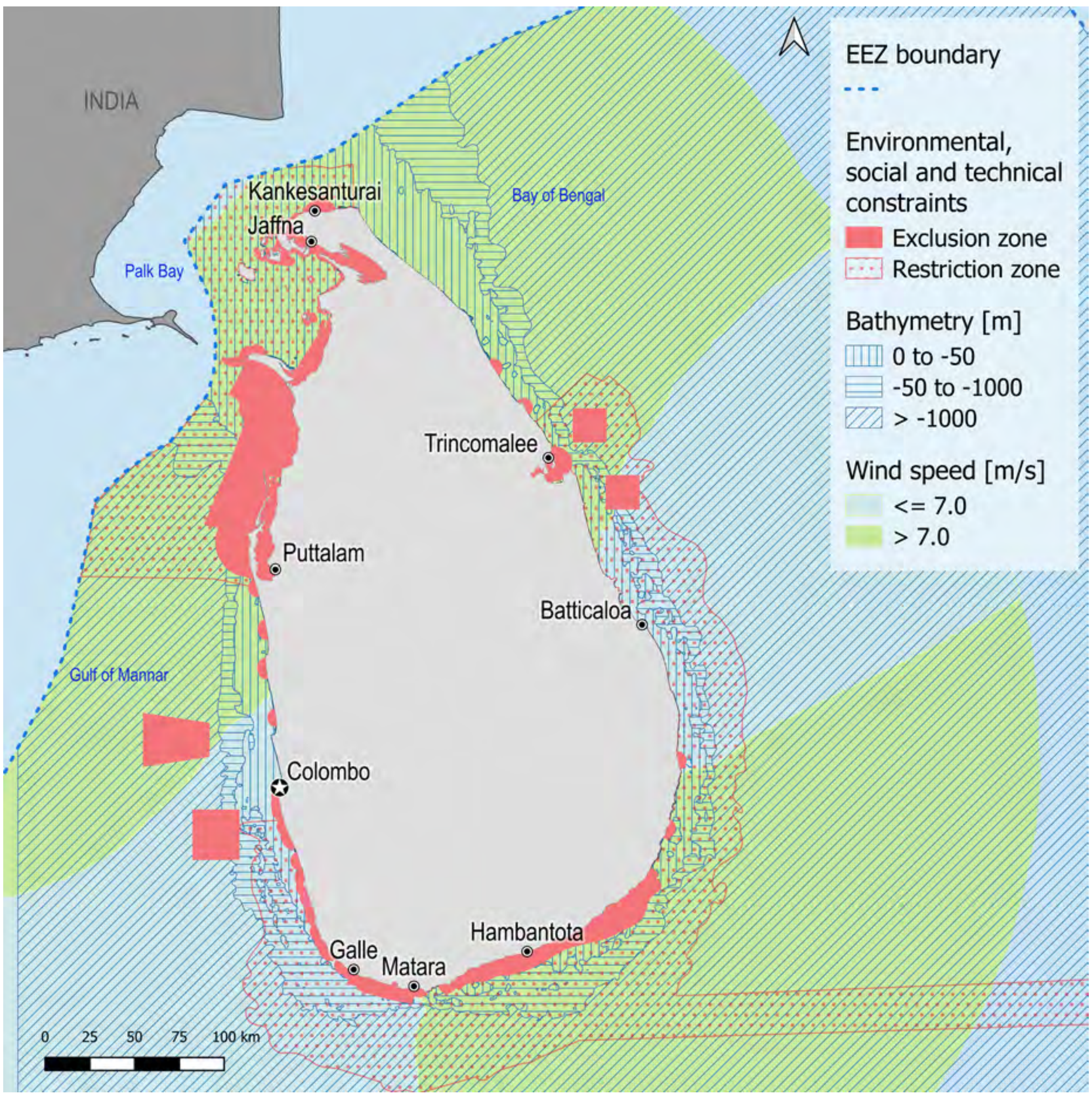


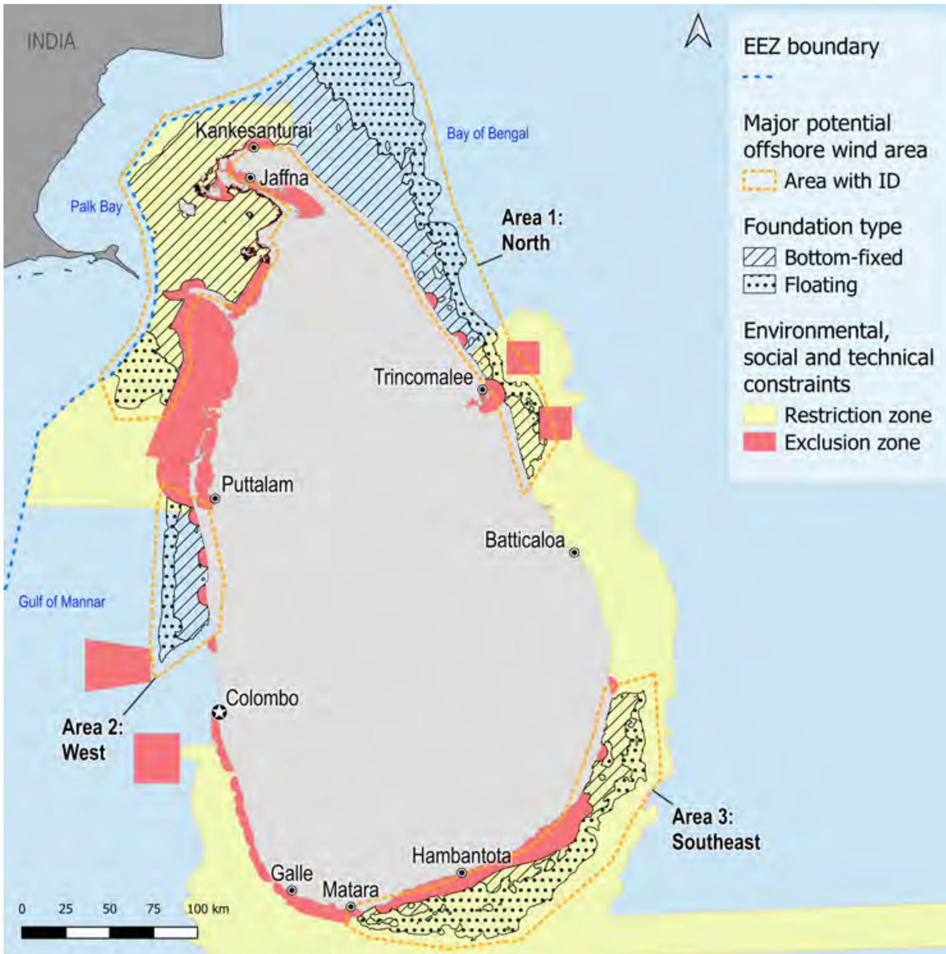
Figure 3.4 shows the most suitable potential areas for fixed and floating offshore wind. These comprise three major potential areas, as labelled in the map.

- **Area 1 (North):**
  - The region to the northeast has fewer E&S constraints, with large areas of shallow water, however the wind resource within this region is less energetic than other regions and there is limited 132kV transmission grid. This area is likely to be a lower priority for development.
  - The region to the northwest (north of Adam's Bridge) has a higher wind resource but some challenging E&S constraints (threatened marine habitats (coral reefs, seagrass, and mangroves), marine mammals, birds, and fisheries). It is far from Sri Lankan ports suitable for offshore wind (as vessels cannot pass Adam's Bridge) but there could be transmission grid connectivity at 220kV on Mannar Island.
  - The smaller region to the south of Adam's Bridge and Mannar Island has some of Sri Lanka's best offshore wind resource, however the area between Mannar Island and Puttalam is a protected marine reserve (with seagrass habitat and dugong) so is not suitable for development. An area further offshore to the west does not have any E&S exclusions but appears to have many sensitivities (especially mammals and birds), so is considered a restriction. Further information is required to better understand this area and its E&S sensitivities. The 220kV transmission grid has been built out to Mannar Island to connect onshore wind generation in the area, and this could potentially be strengthened to connect offshore wind capacity.

- **Area 2 (West):** A coastal area stretching from Puttalam towards Colombo has reasonable wind resource and does not appear to have significant E&S sensitivities. Most of this area is within 25km of the shore, so the visual impact of development will be an important issue. Migratory birds pass through this area as they traverse Sri Lanka's coast, and more information is needed to assess the potential impact of offshore wind on these birds. The steep bathymetry means the water depth increases quickly from shore, limiting this area suitable for offshore wind development. The area is close to the main demand center of Colombo and the 220kV transmission grid is close to the coast. Although it has a reduced wind resource in comparison to other areas, this area appears to have fewer development risks.

- **Area 3 (Southeast):** The region east of Matara along Sri Lanka's southeast coast has the country's highest offshore wind resource. This coastline, however, is a protected marine reserve within an Ecologically or Biologically Significant Area (EBSAs) and Important Marine Mammal Area (IMMA). There is also a UNESCO-MAB Biosphere Reserve around Hambantota. This area is important for blue whales (which have also become a tourist attraction), and a wide range of biodiversity including marine turtles. Offshore wind development in this area is likely to pose a high risk to these sensitivities. The steep bathymetry means there is limited area for fixed offshore wind, and the area is further constrained by the extremely busy shipping lanes to the south. There is limited (132kV) onshore transmission grid in this area, and no transmission grid east of Hambantota. The challenges associated with this area mean that it should be a lower priority for development and further information should be gathered to better understand the E&S sensitivities to inform possible future offshore wind development.

FIGURE 3.4: POTENTIAL AREAS FOR FLOATING AND FIXED FOUNDATION OFFSHORE WIND.



The characteristics of the three major wind potential areas are given in Table 3.2.

TABLE 3.2: CHARACTERISTICS OF MAJOR OFFSHORE WIND AREAS.

	Fixed Potential		Floating Potential	
	km²	GW	km²	GW
Area 1: North	4,564	18	3,697	15
Area 2: West	1,027	4	624	2
Area 3: Southeast	1,336	5	2,947	12
TOTAL	**6,927**	**27**	**7,268**	**29**

Total locational resource potential[8] of the identified areas is estimated at 27GW for bottom fixed and 29GW for floating, considering a WTG density[9] of 4MW/km². This resource potential is much lower than the technical resource potential estimate [20] of 55GW for fixed and 37GW for floating, because initial technical, environmental, and social constraints have been considered [20].

8 The locational potential considers environmental and social constraints and is therefore smaller than the technical potential.

9 This assumes that, on average, 4MW of capacity could be installed per square kilometer. Once projects are built out this density within the project boundary could be higher (often 5-8MW/km²). A lower, conservative capacity density assumption at this stage makes allowance for the large uncertainties in site conditions (especially seabed characteristics and E&S constraints).

In reality, the development of the entire 56GW of resource potential will not be practical, and the amount of offshore wind actually constructed will be far lower. This estimate is relatively high-level and uses existing spatial data. There are many gaps in the available spatial data and so the feasibility of the identified areas has many uncertainties. Future studies and research can help to fill these gaps, providing a better understanding of Sri Lanka's waters and the feasibility of offshore wind development. Furthermore, as offshore wind capacity increases, the cumulative impact of multiple projects will increase and will limit further development. Nevertheless, even if a small fraction of the resource potential identified in this roadmap could be developed, it would provide a large contribution to Sri Lanka's energy mix and presents an attractive new opportunity for the country.

3.2 GROWTH SCENARIOS

To illustrate possible development paths for offshore wind in Sri Lanka, two deployment scenarios have been developed — a low and a high growth scenario. The scenarios are based on feedback from stakeholders, status of the offshore wind industry, statements on the political aspirations of Sri Lanka, and an assessment of the overall potential for offshore wind in Sri Lanka. They were not established or tested through power generation planning or modelling; the roadmap recommends this as one of the priority next steps. Table 3.3 provides a summary of the fixed and floating offshore wind volumes under both scenarios to 2050.

In both scenarios, the period up to 2030 could see the development and delivery of Sri Lanka's first offshore wind project(s). During this time, new skills and expertise would develop in Sri Lanka, forming limited elements of local supply chain capability. The overall size of the domestic supply chain under both scenarios is expected to be relatively small and focus largely on O&M activities.

The main difference between the two scenarios is the capacity volumes, with high growth having approximately twice the volume of low growth. To enable this, the high growth scenarios would require more ambitious policy commitments and larger power demand, either through an interconnector with India or through the development of green hydrogen and other power-to-X alternatives. The affordable delivery of the high growth scenario would also require the development of regional partnerships to fast-track domestic and regional supply chain capabilities (e.g., with China, Vietnam, India).

TABLE 3.3: OVERVIEW OF INSTALLED CAPACITY OF OFFSHORE WIND BY 2050 UNDER THE LOW AND HIGH GROWTH SCENARIOS.

Offshore Wind	By 2030	By 2040	By 2050
Low growth (cumulative)	0.5GW	1GW	2GW
Fixed	0.5GW	1GW	1.5GW
Floating	0GW	0GW	0.5GW
High growth (cumulative)	1GW	2.5GW	4GW
Fixed	1GW	2GW	3GW
Floating	0GW	0.5GW	1GW

3.2.1 Low Growth Scenario

Under the low growth scenario, by 2030, Sri Lanka's first 500MW of offshore wind capacity is established through close collaboration between public and private stakeholders and with financial derisking from international donors and financial institutions. Up to 2GW of offshore wind capacity is installed by 2050. This would be the equivalent of five percent of total system capacity[10] in 2030, and about six percent in 2040, which is considered a reasonable penetration of offshore wind for the Sri Lankan grid.

This scenario assumes that one floating offshore wind project of around 500MW is commissioned between 2040-2050, even though the full fixed bottom potential is not fully utilized. While not currently commercial, floating offshore wind is a rapidly maturing technology and up to a third of all offshore wind installations globally could be floating by 2050. As it can allow deployment further from shore, floating offshore wind can be attractive for countries with coastal tourism as it could reduce visual impact.

To reach such capacity targets, the regulatory framework for offshore wind in Sri Lanka must be developed to ensure transparent and competitive procurement routes to increase interest from the developers. An offshore wind vision or target for 2030 and 2050 should be communicated by the Government, along with clarity on the permitting process and permits required. Furthermore, the government ensures an integrated planning approach including land, coastal, and maritime spatial planning and improves transparency in procurement routes aligned with international practice for the offshore wind. Finally, the government develops initiatives to mobilize the domestic supply chain for offshore wind, including investing in upgrades to a local port.

The overall emissions factor for Sri Lanka's grid in 2022 was approximately 500 grams of carbon dioxide (CO_2) per kilowatt hour (kWh) (abbreviated to CO_2/kWh) [4] and this is expected to reduce to around 400gCO_2/kWh by 2030. Offshore wind is assumed to have a lifetime equivalent emissions factor of 12gCO_2/kWh [21]. 500MW of offshore wind capacity, generating 2,190GWh per year (see section 14.3) could therefore reduce Sri Lanka's carbon emissions by between 0.85 and 1.0 million metric tons of CO_2 per year.

Over the lifecycle of the 500MW of capacity operating by 2030, approximately US$570 million in GVA could be added to the Sri Lankan economy, and up to 25,000 FTE in direct and indirect local employment could be supported. See section 9.3 for further information.

3.2.2 High Growth Scenario

Under the high growth scenario, by 2030, Sri Lanka's first 1,000MW of offshore wind capacity is established in a similar manner to the low growth scenario. Up to 4GW of offshore wind capacity is installed by 2050. Capacity installed under this scenario would be the equivalent of ten percent of total system capacity[10] in 2030, and about 15 percent in 2040. The construction of an interconnector with India could see capacity added exceeding CEB's base case scenario as power could be exported rather than being used to meet local demand. An interconnector would likely be required before 2050 to enable the connection of this volume of offshore wind, alongside other variable renewable energy generation.

Similarly, as with the low growth scenario, the Sri Lankan regulatory framework should be updated to ensure transparent and competitive procurement for offshore wind to increase project developer

10 Assuming the base case scenario for Sri Lankan generation capacity in CEB's (LTGEP) 2022-2041 [4] which estimates a total system of about 9,819MW by 2030 and 15,951MW by 2040.

interest. A higher offshore wind target for 2030 and 2050 should be communicated by the Government, along with clarity on the permitting process and permits required.

To connect this larger volume of capacity, long-term strategic grid planning and necessary reinforcement is required. An interconnector with India would facilitate the integration of this capacity and potentially aid balancing. If this capacity leads to substantial excess generation, when combined with existing planned generation, the business case for the production of green hydrogen and other green fuels (i.e., PtX) can be explored. Regional partnerships to fast-track domestic supply chain (e.g., with China, Vietnam, India) are developed.

In the high growth scenario, LCOE for projects in 2030 is expected to be the same as for the low growth scenario, as both would start with similar developments. The LCOE of projects under the high growth scenario is estimated to fall quicker than the low growth, though the small scale of the industry and projects will limit the economies of scale. It is likely that even if there is a significant pipeline of offshore projects in Sri Lanka, manufacturing supply chain investments are likely to remain elusive, as these will gravitate to the larger multi-GW markets in the region.

Using the same emissions assumptions as section 3.2.1, 1.0GW of offshore wind capacity, generating 4,380GWh per year could reduce Sri Lanka's carbon emissions by between 1.7 and 2.0 million metric tons of CO_2 per year.

Over the lifecycle of the 1.0GW of capacity operating by 2030 approximately US$1,300 million in GVA could be added to the Sri Lankan economy, and up to 57,600 FTE in direct and indirect local employment could be supported. See section 9.3 for further information.

3.3 REGULATORY FRAMEWORK

The analysis of the regulatory framework gives the following main findings also addressed in the main part of this roadmap (see section 8):

1. No dedicated offshore wind regulatory and institutional framework has yet been adopted. It is likely that such legislation will be introduced in the near future following the recommendations of this roadmap and based on the recommendations of other recent international studies. As addressed by the detailed WB and ADB studies [2] [22] [23] [24], the current regulatory framework is in need of an overall reform in order to provide clarity for and support to the development of offshore wind projects.
2. The Sri Lankan regulatory framework may be able to accommodate offshore wind projects to some extent. However, as the existing legal and regulatory system primarily is geared towards smaller scale, onshore renewable projects (compared to the larger-scale offshore wind projects which carry far greater risks), the current legal and regulatory system is unlikely to provide the needed clarity and certainty especially with regard to planning and permitting. This certainty is essential to reduce development risk, thereby enabling developers to invest and also to reduce the cost of financing (and hence the required tariff).
3. The current procurement regime applies a mix of a different procurement routes based on competitive bidding and restricted tenders following international principles and practices. The calls for proposals issued by the SEA and/or the CEB vary in terms of risk allocation and private financing. The call itself sets the specific tender specifications, it provides the details for the PPA and involved tariff structure as preapproved by the PUC. The public undertakes feasibility studies

and may also in some projects include the environmental and social impact assessment (ESIA) to derisk the project. For current large-scale projects based on private financing, a significant risk is allocated to the private developer in undertaking studies, investigations, and the ESIA.

4. From an international perspective, large-scale offshore wind tenders are typically based on procurement routes and auctions involving one- or two-stage[11] competitive tender processes, and a significant involvement of the bidders engaging in constructive, open dialogue with the government to improve the procurement process. The fulfilment of such procurement routes in Sri Lanka is likely to require further capacity to navigate such resource demanding processes.
5. The permitting regime is complex in terms of consenting authorities involved and coordination. The developer is typically responsible for obtaining all consents, permits, and licenses. The SEA provides some assistance in coordination but takes no responsibility. This places substantial risk on the developer and uncertainty on the consents required and the timeline to obtain them.
6. In addition, the offshore wind permitting regime and the underlying studies and investigations relate to the need for robust baseline surveys and the ESIA to be completed to GIIP, and it relates to the alignment of regulatory framework and permitting to lender requirements to avoid delay in financing. These aspects need to be taken into account by the SEA, the CEB, the PUC, and also the SEA when setting the conditions and tariff structures for the particular offshore wind tender.

3.4 FINANCIAL AND ECONOMIC ANALYSIS

The cost of energy from offshore wind in Sri Lanka could be competitive with new thermal generation but requires access to lower-cost international financing, as well as sufficient risk mitigation measures. The cost of power generation in Sri Lanka is high, and the cost of new LNG fired generation is expected to be between US$90 and 120 per MWh (equivalent to 9 to 12 US Cent/kWh, see section 2.2).

Assuming access to low-cost concessional finance and sufficient risk mitigation can reduce the cost of capital (WACC) to around six percent, the LCOE for Sri Lanka's first project could be between US$75 and 90 per MWh, depending on the wind resource. Even if this low cost of capital cannot be achieved, a more reasonable WACC of ten percent would result in an LCOE of around US$110 to 120 per MWh, which would still be competitive with new LNG fired generation.

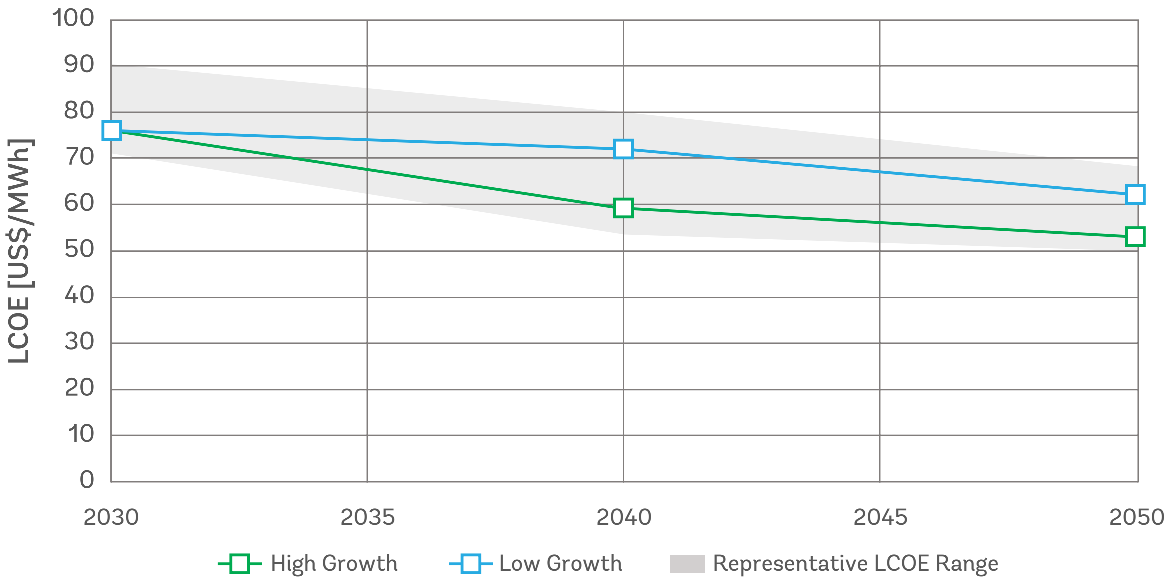
Risk mitigation and regional cooperation will help to reduce LCOE. Offtake guarantee instruments and foreign exchange hedging facilities, for example, will help to reduce a project's commercial risks, thereby reducing the cost of financing and LCOE. As the Indian offshore wind industry develops, a local/regional supply chain may establish and could provide equipment and services at a lower cost than importing from international markets. The combined scale of Indian and Sri Lankan projects will also make a more attractive opportunity for supply chain investment.

Under the two growth scenarios, the LCOE of Sri Lankan offshore wind projects could drop to US$60-70 per MWh in 2040 and US$50-60 per MWh in 2050. The LCOE of the first offshore wind capacity in any new market will be higher than subsequent capacity as risks reduce with experience. These cost reduction trajectories are equivalent to 20 to 30 percent reduction in LCOE by 2050 relative to 2030, and are shown in Figure 3.5. These trajectories are heavily dependent on the cost of capital and the available wind resource. The cost reduction potential is relatively modest; project sizes

11 One stage in Denmark and the Netherlands. Two stage in the UK; one for obtaining the lease arrangement and a second for obtaining revenue support, see also World Bank Group's 2021 report "Key Factors for Successful Development of Offshore Wind in Emerging Markets", at p. 35ss. [17].

are likely to be small (<1GW) so economies of scale will be limited, and the overall market size is also relatively small and insufficient to stimulate substantial local supply chain growth. See section 2.3 of the Key Factors report [17] for further information on LCOE and cost reduction.

FIGURE 3.5: LCOE TRAJECTORIES IN THE LOW GROWTH AND HIGH GROWTH SCENARIOS, INCLUDING A RANGE OF REPRESENTATIVE LCOE DUE TO UNCERTAINTIES.



The majority of financing for offshore wind projects will be provided by international investors. The capital expenditure (CAPEX) of a 500MW offshore wind project is typically US$1,250 million. Under a typical limited-recourse project financing structure, around US$1,000 million of the CAPEX would be bank debt. The cost of capital from local banks in Sri Lankan Rupees could be as high as 15 percent and there is limited liquidity available locally. International lenders will be able to provide sufficient volumes of debt, with more favorable terms, however this will be contingent on the mitigation of a range of risks affecting the bankability of projects, some of which include:

- **Environmental and social risks** – the majority of potential sites in Sri Lanka have notable E&S sensitivities. An ESIA which meets international lenders' requirements will help to identify and mitigate this risk.
- **Grid connection agreement** – connection of generation at this scale will be technically challenging for Sri Lanka's grid. Sufficient provisions will be required to address the risk of connection availability and establish appropriate compensatory mechanisms.
- **Power purchase agreement (PPA)** – a long-term PPA will be required to provide revenue certainty. The PPA's terms, especially compensation for curtailment, will be critical to the bankability of the project. The PPA's terms will need to recognize the differences between offshore wind and other generators.

- **Offtaker creditworthiness** – lenders will need confidence in the offtaker's ability to cover its payment liabilities over the lifetime of the PPA. Government backstopping to guarantee the PPA is likely to be required.
- **Political risk** – lenders will investigate the likelihood and implications of policy, regulatory, and contractual amendments that could be made by future governments and whether that could impact the project's expected revenues. Insurance may be required to cover this risk.
- **Exchange rate** – the future exchange rate of the Sri Lankan Rupee is unknown, and its volatility will impact revenues to service foreign debt unless sufficiently mitigated through some form of hedging or other instrument. Given the recent currency devaluation, this will be a major consideration.

See section 3.6 and 4.5 of the Key Factors report [17] for further discussion on the bankability of offtake agreements and the financing of offshore wind in emerging markets.

The development, construction, and operation of offshore wind projects could provide substantial benefits for the Sri Lankan economy. The gross value added (GVA) from offshore wind investments of different sizes is illustrated in Table 3.4. The chart shows the impact on GVA from offshore wind projects over their lifetime sorted by the expected time of commissioning. Between 2020 and 2030 it is expected that 0.5 to 1GW offshore wind capacity will be commissioned. During construction and over 25 years of operation these projects will generate between 570 and US$1,330 million in GVA in Sri Lanka.

TABLE 3.4: ESTIMATES OF CUMULATIVE, LIFETIME GVA FROM DIFFERENT OFFSHORE WIND CAPACITIES UNDER THE TWO GROWTH SCENARIOS IN 2030.

	Direct Investment (US$ million)	Indirect Investment (US$ million)	Total Impact on GVA (US$ million)
Low Growth scenario (500MW)	380	190	570
High Growth scenario (1GW)	880	450	1,330

The total direct and indirect local employment associated with the development, construction, and operation of 500MW of offshore wind is estimated as around 25,000 FTE.

In terms of local value creation, there is a big difference between CAPEX and OPEX. While the construction of the OWF will take place within a short timeframe, O&M continues over at least 25 years. Thus, **fewer full-time employees will be needed to deliver the FTEs from O&M compared to construction**.

TABLE 3.5: LOCAL EMPLOYMENT EFFECT FROM OFFSHORE WIND INVESTMENT.

	Direct FTE	Indirect FTE	Total FTE
Low Growth scenario (500MW)	15,600	9,100	24,700
High Growth scenario (1GW)	36,200	21,400	57,600

3.5 HEALTH AND SAFETY

Before offshore wind can be developed and constructed in Sri Lanka, clear health and safety policies and rules governing offshore wind will need to be put in place. This should include requirements for contractors delivering services during surveys, construction, and O&M building on, for example, European experience and Global Wind Organisation (GWO) standards — discussed further in section 3.8 of the Key Factors report [17]. This statement should be drafted by local health and safety experts, but would benefit from guidance and support from international offshore wind health and safety experts. It is important to incorporate clear health and safety requirements for contractors delivering services during surveys, construction, and O&M. It is imperative that the right level of health and safety expertise is attracted to the project at an early stage.

Currently, Sri Lankan health and safety legislation appears to be limited to acts and regulations prepared by the Ministry of Health, and the Occupational Health unit regulating on child labour, worker compensation, maternity benefit ordinance, and the like. Additionally, the National Institute of Occupational Safety Act, No. 38 of 2009 established the "National Institute of Occupational Safety and Health" (NIOSH) — a statutory board which operates under the ministry of labour and trade union to advise the Sri Lankan government on its national occupational health and safety (OHS) policy. Furthermore, NIOSH supports the government within a range of services including prevention of accidents and incidents, use of equipment, OHS hazards, OHS training and legislative requirements, as well as publishing information relating to OHS. **Based on the limited regulation within OHS, it will be relevant to base the OHS requirements in contracts within the wind industry on recognized international standards.**

Through the planning of future exploration and extraction of offshore hydrocarbons, PDASL and other Government entities are developing new health and safety regulations. It is expected that these will be largely based on the principles employed in the UK and Norway, and that some of these regulations will be applicable to offshore wind activities. This initiative could benefit the development of offshore wind as it would help to educate regulators (and local workers) on the risks associated with the offshore environment, as well as emphasizing the importance of safety while working offshore.

3.6 GRID INFRASTRUCTURE

Sri Lanka has been improving the coverage of electrification over the past decades. However, at the moment, the northern and northwestern region have areas without access to electricity. Low population or industrial density can be the reason of the low transmission network maturity. In the generation and transmission development plan (short- and long-term), there is some focus on building more onshore wind power plants and the transmission system to evacuate the wind power.

The existing plan has not taken into consideration the development of offshore wind, nor upgrades to the transmission network to cope with these power plants. A typical offshore wind farm is typically rated between 500MW to 1GW and is significant when compared with the national installed capacity of 4.2GW. Any changes in the active or reactive power exchange due to a fault with a generator of this magnitude would create significant frequency and voltage variations on the electricity system. With the existing system, and the fact that it is an island grid, there is no chance to properly control, damp the oscillation, and put the system back into normal.

When planning the development of offshore wind in Sri Lanka, from a grid connection perspective, the most important goal is to properly align the wind farm's production with the consumer demand. **Considering the electricity cannot be consumed locally, the transmission network must be built and reinforced as needed, to transport the electricity to the demand centres.** These centres can be industrial regions, residential areas, pump-reserve facilities and the potential grid connection with India.

The electrical grid connection studies and simulations must be performed throughout the whole development and permitting process. They will tell with the current and future infrastructure whether the planned wind farm can be connected, whether there is any restriction in operation, and what needs to be done to remove the barriers. The tailored offshore wind farm grid connection requirement must be discussed, drafted, and put in force. As an island country with an isolated and vulnerable network, special attention must be paid on electromagnetic transient analysis. Some markets with successful offshore wind experiences, such as the UK and Taiwan, can be a useful reference for the planning and operation of grid with large scale offshore wind generation.

3.7 PORT INFRASTRUCTURE

Of Sri Lanka's four major ports, two — Colombo and Hambantota — are suitable to support the installation of bottom-fixed offshore wind with only minor upgrades. Major upgrades, primarily dredging and creation of storage yards, would be required to use the ports of Trincomalee and Kankasenuthurai. The port of Hambantota, in particular shows great potential for offshore wind installation, as it has ample lands behind the port remaining for development and a development concept which includes hinterland industrial zones.

In terms of installation ports for floating foundations, the port requirements differ greatly among different floating foundation concepts even though there are only a few leading floater technologies. Due to these differences and lack of installation track record, a global, representative port requirements benchmarks for floating wind installation cannot yet be derived.

Area 2 (West) and Area 3 (Southeast) can be well served by Colombo and Hambantota ports. Area 1 (North) is less well served for two reasons; firstly, the chain of limestone shoals between Sri Lanka and India (called Adam's Bridge) forms a natural barrier to ship traffic in the northwest corner of Sri Lanka; secondly, the ports in the west and northwest of the country — Trincomalee and Kankasenuthurai — will need major upgrades to serve as offshore wind installation ports. To be economically feasible, such upgrades would require a large volume of offshore wind, such as the volume expected for 2040-2050. With the smaller volumes expected in the short term, solutions with feeder barges (rather than a classical full-service installation port) can be explored on a project-specific basis. It may also be possible to use Indian ports, such as Tuticorin, for wind farms south of Adam's Bridge.

The suitability of each potential port for offshore wind is summarized in Table 3.6.

TABLE 3.6: SUMMARY OF SUITABILITY OF POTENTIAL PORTS FOR BOTTOM-FIXED INSTALLATION.

	Port Suitability	Comments
Colombo	Suitable, with minor upgrades	• Ownership: government • Sri Lanka's port, primarily serves container shipping • Ideally suited to serve Area 2, parts of Area 1 and 3 are within range • Port is running at capacity with plans to expand • Sufficient yard area exists and is ideally located, but is currently in use for other purposes and would need to be made available
Galle	Not suitable	• Ownership: government • Used as port for commercial leisure activities with further developments in this direction planned • Less than minimum berth length and lack of any yard area or the possibility to develop an adjacent yard make this port unsuitable for offshore wind installation
Hambantota	Suitable, with minor upgrades	• Ownership: public/private joint venture • Can serve Area 2 and Area 3 • Conceptualized as a large complex with port services and industrial areas behind the port; core is operational with excellent options for expansion
Trincomalee	Suitable with major upgrades	• Ownership: public • Various terminals are located scattered within a large natural harbour • Can serve most of Area 1 and a good portion of Area 2 • Ashroff Jetty would likely require a large expansion to enable component transport and creation of yard area
Kankanesunthurai	Suitable with major upgrades	• Ownership: public • Port is not suitable in its current state, but developments are underway and would close some of the suitability gap • Major upgrade to create adequate yard area and dredging works would additionally be required

With installation volumes of up to 1GW in the high growth scenario, one installation port could cover the entire volume, given the right location and staggered installation. If the entire installed volume is built within Area 1, it is also conceivable that all the installations could be done with a feeder barge system, if the economics and logistics of the projects allow, greatly reducing the need for upgrades to port infrastructure.

Due to the anticipated moderate volume of offshore wind expected, it is also important that any upgrades made to the ports for offshore wind are also designed with a multi-functional use, taking potentially relevant E&S issues into consideration. The upgrades should not serve only offshore wind alone, but also give an added value to the port between offshore wind installation cycles.

Any port development should be considered with the development of Indian offshore wind projects in mind. Projects being planned in Tamil Nadu represent a large opportunity for Sri Lankan ports (and industry). An upgraded port suitable for offshore wind marshalling and installation may also serve some of the Indian development. It is likely that ports in Tamil Nadu, such as Tuticorin, will also be upgraded, however the scale of the development in the region (especially if Sri Lankan projects are included) could require multiple construction and marshalling ports.

3.8 SUPPLY CHAIN

Currently, Sri Lanka has no track record in offshore wind, but has some capabilities in related sectors, such as onshore wind and onshore electrical infrastructure as well as offshore oil and gas projects. Offshore wind projects can benefit from Sri Lanka's local expertise in permitting and project development, along with operation and maintenance activities of these infrastructure projects.

There are relatively few benefits for projects to source locally for many of the equipment/materials necessary to build and operate an offshore wind farm because they either carry relatively large investments with significant risk, or there is a well-established international (European, Indian) capacity to meet the demand which would be difficult for Sri Lankan companies to naturally compete with. The overall size of the Sri Lankan electricity market seriously limits options to develop the local supply chain, and local investments would need to be based not only on the needs of the Sri Lankan market, but also on serving the Indian and regional markets.

The rankings, based on metrics keeping alignment with similar roadmaps from other countries in the World Bank Group's roadmap series, are explained in more detail in section 13.8 (see Table 13.2). The assessment considers five factors and was made in consultation with local stakeholders.

The current state of the supply chain is reflected in Table 3.7. The scoring reflects that there is overall a number of areas where Sri Lanka has capabilities in parallel sectors, such as onshore wind and heavy construction, however, lacks offshore experience in the same areas. In general, offshore wind projects would benefit most from Sri Lankan expertise in permitting and project development, along with operation and maintenance activities for the offshore wind farms. There are relatively few benefits to projects to source locally for many of the other items because they carry significant investment risk or there is a very established international capacity to meet the demand which would be difficult to compete with.

TABLE 3.7: EVALUATION OF SRI LANKAN SUPPLY CHAIN READINESS.

Category	Local Notable Companies	Country Track Record and Capacity in OSW	Sri Lanka Capability in Parallel Sectors	Benefits of Sri Lanka Supply	Investment Risk in Sri Lanka	Size of the Opportunity
Developing and permitting	WindForce, LTL Holdings — Ceylex Renewables	1	3	4	2	2
Nacelle, hub, and assembly	-	1	1	2	2	4
Blades	-	1	1	2	2	4
Tower	-	1	1	2	2	4
Foundation supply	Columbo Dockyard, Access Engineering	1	2	2	2	4
Array and export cable supply	-	1	1	2	2	4
Offshore substation supply	DIMO	1	2	2	2	3
Onshore infrastructure supply	Access Engineering, DIMO	1	4	3	3	1
WTG and foundation installation	-	1	1	1	4	2
Array and export cables installation	ACL Cables, DIMO	1	2	2	3	4
Wind farm operation	WindForce, LTL Holdings	1	3	4	4	4
WTG maintenance and service	WindForce, LTL Holdings	1	3	4	4	4
Balance of Plant (BoP) and various maintenance	Access Engineering, DIMO	1	3	4	4	4
Decommissioning	Access Engineering	1	2	4	4	2

The moderate volume of offshore wind expected in Sri Lanka does not give natural incentives to localize the supply chain. This is directly reflected in the assessment of supply chain, where project development (likely to be a joint venture between local companies and international developers) and operation and maintenance show the greatest benefits in local sourcing. The other areas, which primarily compose the purchased parts, are classified as low-level local benefit because the capital and workforce investments needed to establish these parts of the supply chain in Sri Lanka cannot be recouped by the foreseen volumes. The supply chain benefits are likely to flow to neighbouring India, which has a significantly larger market size, and more advanced manufacturing capabilities, and exports that align closely with, and already support the global wind industry.

Experience in offshore wind markets such as France and Taiwan has shown that government imposed local content requirements increase tariffs, development risks, and the potential for delays. It is therefore advisable to avoid local content requirements but instead to offer incentives or initiatives to stimulate local industrial opportunities. In the coming years, the offshore wind industry is expected to become a seller's market as many countries have announced ambitious offshore wind goals within the 2030 timeframe and beyond. In this environment, countries which make the development of offshore wind farms easy will have a competitive advantage, and vice versa.

Investments in the Sri Lankan offshore wind supply chain must consider local needs, but also the needs and development pace of the of the larger Indian and regional markets. If Sri Lankan companies gain experience and capability in offshore wind through national projects, this may enable them to serve the export market more effectively in the long term. In the short term, however, Sri Lankan exports are not aligned in type or scale to support a large, regional, offshore wind value chain.

4 PATHFINDER PROJECT

The implementation of a pathfinder project is a pertinent way of kicking-off the industry and showcasing to the wider public how offshore wind can start to build out. The size of the pathfinder project needs to strike a balance between several factors: the size and nature of Sri Lanka and its grid may call for smaller projects, while wind farms of larger size would be more attractive to developers and could help to reduce costs. Even though the Sri Lankan grid is an isolated island grid with no interconnections yet, a larger project is recommended to create a better business case. To provide a large-scale contribution to Sri Lanka's 2030 renewable energy target, a 500MW pathfinder project has been chosen as reference case and summarised in this section and discussed further in section 14.

4.1 LOCATIONS FOR A PATHFINDER PROJECT

The considered options (further described in section 14.1 of this roadmap) for the location of a pathfinder project have been selected based on the following considerations:

- Water depth allowing for fixed foundations (i.e., <50 meters)
- High wind speed
- Not in an environmental and social exclusion zone
- Good grid connection possibility
- Accessible from a port suitable for installation activities

In summary, the three options as depicted in Figure 3.4 are:

- **Option A: Gulf of Mannar.** This area is located around the northern tip of the country and is characterised by a good wind resource and water depths that are, to a large extent, below 50m allowing for fixed foundation solutions. However, there is a "natural" restriction in the form of Adam's Bridge — a chain of natural limestone shoals creating very shallow waters which cannot be passed by larger vessels — thereby cutting off a large part of the area when considering a pathfinder project. There are many E&S restrictions in this area and further information is required to assess whether development may be possible with sufficient mitigation.

- **Option B: Puttalam.** This area has lower risk in relation to environmental and social constraints, and it is located close to the principal demand center and port of Colombo. However, the wind resource in this area is slightly lower than Option A or C, with average wind speeds in the range of 7.5-8.5m/s.

- **Option C: Hambantota.** This area has good average wind speeds of 8-9m/s however, the suitable area for fixed offshore wind is smaller and more disparate than in the Gulf of Mannar and therefore, the potential for extensions of a potential pathfinder project is limited and more complex. This area also has numerous highly sensitive E&S issues and has poor access to transmission grid, though upgrades are planned.

From a "rough screening" point of view considering water depth, wind resource, and environmental and social constraints, Option A and Option C are quite similar. Option B has the advantage of fewer risks in relation to environmental and social constraints but shows slightly lower wind speeds.

TABLE 4.1: OVERVIEW OF KEY CONSIDERATIONS FOR THE THREE OPTIONS FOR LOCATION OF A PATHFINDER PROJECT.

Option	Water Depth Less Than 50m	Wind Speed	Environmental and Social Constraints	Grid Connection	Nearest Major Port
A North	Yes	8-9m/s	High risk (within EBSA & IMMA)	220kV line	Colombo
B West	Yes	7.5-8.5m/s	Lower risk	220kV line	Colombo
C Southeast	Yes (limited)	8-9m/s	High risk (within EBSA & IMMA)	220kV line (to be constructed)	Hambantota

Options A and C both feature substantial environmental and social sensitivities. A UNESCO-MAB Biosphere Reserve is located around Hambantota and a protected marine area runs along the southeast coast, meaning that the electrical export system from any project in the Option C area would need to pass through this. Furthermore, the onshore grid in this region is weak (though there are plans to improve it) and, although metocean conditions have not been investigated in this roadmap, the southeast coast will be exposed to more severe wave conditions. Option C also has unknown bathymetry, but with indications of a steep seabed that deepens quickly. There may be some shallower water in this area, but it is likely that much of it will be deeper and only suited to floating wind turbines.

While Option B has a less energetic wind resource, it appears to have fewer environmental and social sensitivities. It is also close to the port of Colombo and to existing transmission grid.

Options A and B in the Gulf of Mannar are closest to India and could offer synergies with the planned offshore wind projects in Tamil Nadu. Cooperation with India in this region could be essential in bringing the benefits of large-scale development to Sri Lanka.

From the information available on these three areas, Option A (Mannar) and Option B (Puttalam) appear to be more favorable for Sri Lanka's first offshore wind project and it is recommended that the feasibility of both areas is investigated further.

As Option A, Mannar, has a higher wind resource, it is likely to have a lower LCOE than a project at the Option B, Puttalam location. For this reason, this analysis focuses on Mannar as a possible location of a pathfinder project. To achieve some economies of scale, and provide a project scale that is attractive to investors, a 500MW pathfinder project has been assessed.

A rough estimate of the annual energy production (AEP) from a 500MW pathfinder project located in the Gulf of Mannar south of Adam's Bridge using a 12MW wind turbine generator (WTG) has been estimated as outlined in Table 4.2. The gross energy production is presented, followed by the consideration of the wake losses, which are the energy losses caused by a reduction of wind speed caused by the wake of a wind turbine and impacting downwind turbines. Finally, further system losses are considered to derive the net AEP.

TABLE 4.2: AEP ESTIMATE FOR 500MW PATHFINDER PROJECT IN THE GULF OF MANNAR.

Wind speed	8.8m/s
Nos. of 12MW WTGs (150m hub height)	42
Annual gross energy production (P50)	2,535GWh
Wake loss (assuming 4.0%)	101.4GWh
Annual gross energy production (P50) (including wake losses)	2,433GWh
Gross capacity factor	55.1%
Other losses — electrical, outages, etc. (10% of P50)	243GWh
Net Annual Energy Production (AEP)	2,190GWh
LCOE[12]	US$75/MWh

It must be noted that this estimate is highly uncertain as it is based on an unoptimized layout with losses only roughly estimated. Furthermore, it does not take into account any uncertainties, so this should be considered as a high-level, preliminary estimate which inherently will change once the optimization process and detailed analyses have been carried out.

Using the CAPEX and OPEX assumptions from the financial analyses in section 9.1 including a target WACC of six percent (which is heavily contingent on concessional finance and sufficient risk mitigation) and applying a net AEP of approximately 2,190GWh per year for the 500MW pathfinder project, yields an LCOE of around US$75 per MWh.

4.2 PROCUREMENT OPTIONS

The development of offshore wind is completely different to that of onshore wind or solar. The development timeline, cost, and risk are all much greater, so a specialized approach to development and procurement is required to help encourage investment and to drive down costs.

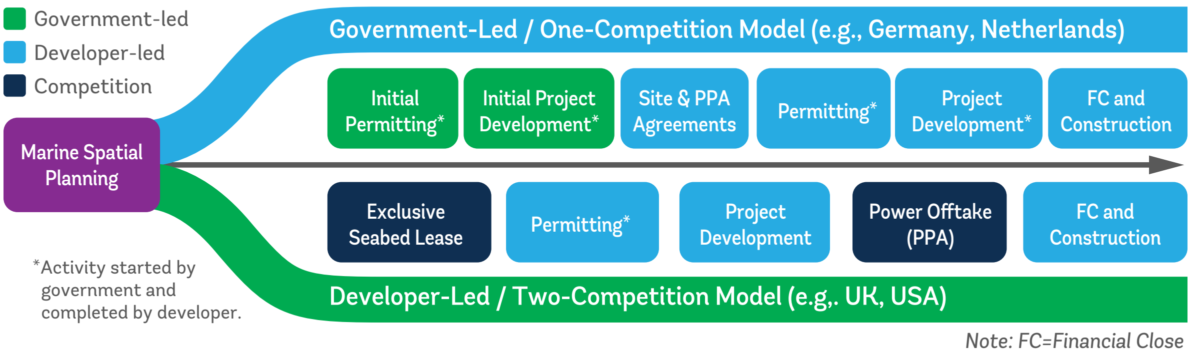
Broadly, there are two types of competitive procurement models (see Figure 4.1 and section 3.2 of the Key Factors report [17] for further discussion) that have evolved and are used by established offshore wind markets.

1. **Government-led approach:** A government takes responsibility for the site identification and early development work, usually including in-principle permits, to prepare a project that can be used in a price/tariff-based auction. The development work is required to give bidders enough information and sufficient data to estimate a competitive price of power. The amount of uncertainty at the time of bidding will directly impact the bid price. As this approach only has a single competition, it is sometimes known as the one-competition model.

12 Assumptions on CAPEX and OPEX are the same as described in Table 9.1 scaled to 500MW. The LCOE is based on a target WACC of six percent which depends on sufficient risk reduction and the use of concessional finance.

2. **Developer-led approach:** A government provides some guidance on preferred areas for development and runs a competition to award project developers with exclusive rights to explore offshore areas. Developers are then responsible for gathering data, developing a project, and obtaining permits, before they bid into a tariff-based auction. As this approach has two separate competitions (for a seabed lease and for a tariff/offtake agreement), it is sometimes known as the two-competition model.

FIGURE 4.1: OVERVIEW OF ACTIVITIES, COMPETITIONS, AND RESPONSIBILITIES UNDER THE ONE- AND TWO-COMPETITION MODELS FOR OFFSHORE WIND PROCUREMENT.



Source: World Bank Group, adapted from Figure 3.3 in Key Factors report [17].

The two-competition model can work well in large markets, where many GWs of projects are under development. The design of the competitions, including the rates at which sites and PPAs are awarded, can be used to ensure that there is a sufficient number of developers and projects participating to create competitive tension at lease and power offtake competitions.

The one-competition model is more applicable when there is appetite for a government to closely control and take the risk of development, and in cases where there is limited competition for leases or offtake agreements. A government-led approach can also be helpful in reducing risk before awarding projects to private developers, thereby reducing the risk that is borne by developers and potentially helping to reduce costs and delays.

Sri Lanka may require around 1GW of offshore wind capacity in the medium-term. In the context of offshore wind, this is a small market opportunity and could likely be delivered by one to three projects. Projects of 500MW or larger will benefit from economies of scale and will have a lower cost of electricity. This volume will not create sufficient competitive tension to successfully run a two-competition model. **WBG therefore recommends that a one-competition model is used to procure Sri Lanka's first offshore wind projects.** This approach has the advantage of delaying the participation of private sector developers, thereby allowing the country's economic climate to recover before encouraging international investment.

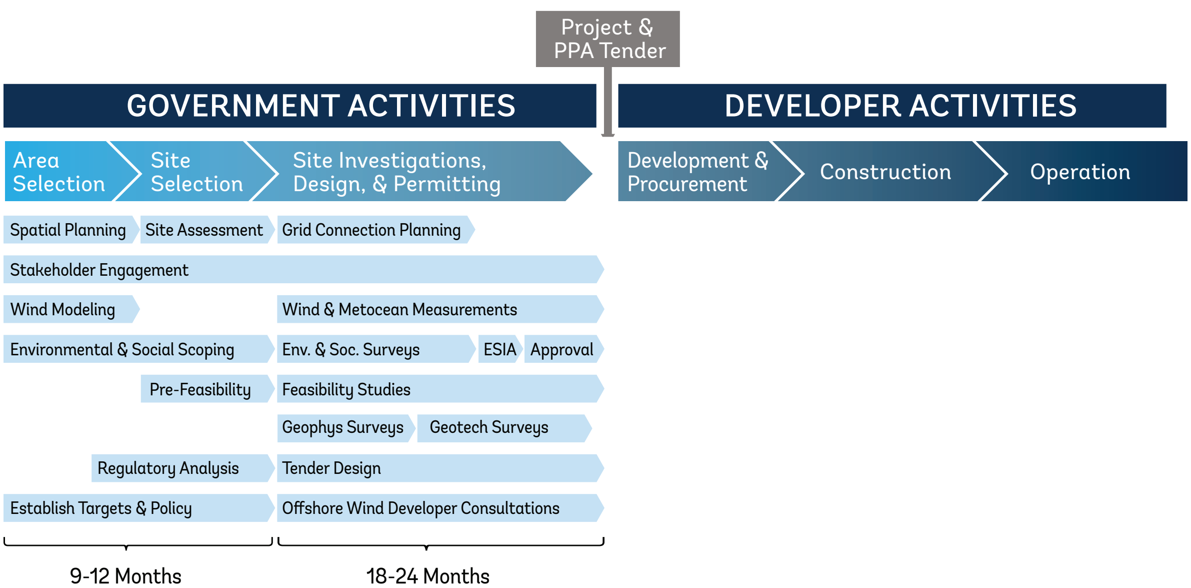
4.3 NEXT STEPS FOR DEVELOPMENT OF A PATHFINDER PROJECT

Currently, Sri Lanka employs a mixed approach for tender processes related to renewable energy projects by setting the tender specifications and requirements depending on the particular tender. Currently, the lack of offshore wind regulatory experience and the lack of an offshore wind dedicated legal framework indicate that the process predominately should be government led in order to derisk the project.

As previously mentioned, the development of offshore wind projects takes considerably longer than for onshore renewable energy projects. To avoid delays and higher costs, it is also important to focus on quality and risk reduction to ensure that data and development work can be relied upon by developers bidding into the future tender.

Figure 4.2 summarizes the main phases in the development and delivery of an offshore wind project under a government-led procurement model. The diagram focuses on the government-led development and preparatory activities that need to occur before a project tender, along with an estimated timeline for this work. The timelines are approximate and will vary depending on the availability of resources and the scope and sequencing of activities, which will be informed by the findings of previous tasks.

FIGURE 4.2: REPRESENTATIVE TIMELINE FOR TYPICAL GOVERNMENT-LED DEVELOPMENT ACTIVITIES AHEAD OF A PROJECT TENDER COMPETITION.



WBG recommends the following short-term (9-12 months) actions to progress this preparatory work:

1. **SLSEA and PDASL** sign a Memorandum of Understanding, formalizing their cooperation on offshore wind, declaring at least the two areas (Mannar and Puttalam) as a priority for potential offshore wind development, and establishing a common block definition across Sri Lanka's waters.
2. **SLSEA** develops and publishes (or Gazettes) a policy for offshore wind, stating a target capacity, timeline, and the chosen procurement model.

3. **WBG** commissions technical assistance work to inform decision-making, including;
   - Environmental and social analysis to:
     - Identify key stakeholder groups
     - Commence initial stakeholder engagement
     - Gather additional existing spatial data on environmental and social issues
     - Update spatial planning work commenced under this roadmap
   - Wind analysis using mesoscale models and incorporating existing onshore/coastal measurements of data, especially from Mannar Island
   - Grid connection assessment in collaboration with CEB to identify potential options for connection locations and capacities
   - Regulatory gap analysis and recommendations on any required amendments to deliver the government-led procurement model
   - Prepare a detailed scope of works and costing for site data collection, feasibility assessment, and tender design, to be delivered under a grant executed by SL government with WB support.

As Figure 4.2 shows, this initial phase of preparatory work informs a longer phase of site surveys and detailed studies. The activities under this phase of work are required to reduce project development risks and provide more certainty about the project before it is tendered. These activities include;

- **Geophysical investigations** — surface investigations which characterize the seabed (depth, bathymetry, structure, objects, and hazards e.g., UXOs). Depending on the resources available, this may also include targeted geotechnical investigations.
- **Metocean study** comprising location (coordinates) and general site description, bathymetry and tidal data, wind data, and wave data.
- **Site-specific wind study** including data collected on site for at least 12 complete months.
- **Environmental and social scoping** and initial assessment, including baseline studies that cover multiple seasons and/or annual cycles — typically, bird and marine mammal surveys should span at least two years. Stakeholder engagement should also inform the scoping and assessment. This information is used as the basis for a project-specific environmental and social impact assessment (ESIA) which could either be carried out by the government (providing in-principle permits) or later by the selected developer.
- **Grid integration study** analyzing the grid code requirements and the possible need for reinforcement/upgrade of the existing grid transmission system or any extensions if necessary.
- **Port study**, analyzing existing available ports and specifying the needs for upgrades.

Although limited in number, the required studies will typically take around 18 to 24 months to prepare and undertake as the data collected needs to be of sufficient quality and gathered over a long period in accordance with good international industry practice (GIIP). Section 15 also provides further information on specific studies and surveys, as well as providing rough cost estimates. While these site surveys and studies are progressing, the government should design the tender competition, in consultation with the industry, and publish the process and rules well ahead of the competition date.

5 OPPORTUNITIES AND CHALLENGES

This wide-ranging roadmap examines many facets of a potential offshore wind industry and presents recommendations and plans for realizing it. In the Sri Lankan context, some of these plans and recommendations will be particularly challenging, while some others will present opportunities that can only be achieved with offshore wind. This chapter describes the most important of those opportunities and challenges.

5.1 OPPORTUNITIES

- **Offshore wind could help Sri Lanka to achieve the goal of 70 percent renewable energy.** As individual onshore wind and solar PV projects in Sri Lanka to date have tended to be small, and land is a precious resource, their deployment rate could be insufficient to fully meet the 2030 target. Offshore wind has the potential to provide a large-scale contribution to help achieve the government's decarbonization targets, especially in the longer term.
- **Offshore wind opens the opportunity to export renewable energy to India and regionally** since Sri Lanka has potential to generate more electricity than consumed domestically. A planned interconnection with India could offer access to regional electricity markets, thereby providing large-scale income for Sri Lanka.
- **Around US$570 million in GVA could be generated for the Sri Lankan economy over 25 years** through the development, construction, and operation of 500MW of offshore wind.
- **Power-to-X (PtX) options, such as green hydrogen and ammonia, could offer alternative future uses for offshore wind generation.** This could include the decarbonization of local industry and existing hydrogen consumers, production of green shipping fuels for vessels calling at Sri Lanka's ports, or potentially for export as an appropriate energy vector. That said, due to the high production costs, this is a longer-term opportunity and is unlikely to feature in the business case for the country's first projects.

5.2 CHALLENGES

While there are numerous challenges to developing offshore wind, these are common to many countries looking to deploy this technology for the first time. Some of the main challenges include:

- **The country is currently experiencing a severe economic crisis.** Unable to service its high debt costs, it announced a debt default in mid-2022. A large trade imbalance, exacerbated by expensive fossil fuel import costs, contributed to the crisis. Transitioning to renewable energy and thereby reducing fuel imports is expected to be an important action in the country's recovery.

- **Offshore wind has a higher cost than onshore wind and solar PV which could lower interest to start developing the offshore wind industry in a timely manner.** However, the realizable potential of onshore renewables may not be sufficient to meet the country's energy needs and decarbonization objectives by 2030 and beyond. Since offshore wind is an attractive option to ramp-up renewable generation in Sri Lanka, the development of both onshore and offshore renewables needs to be viewed holistically to reach the country's ambitious goals.
- **The domestic supply chain potential is limited.** Sri Lanka would therefore be highly dependent on international suppliers and developers for equipment and materials. The relatively small volume of offshore wind expected in Sri Lanka itself does not offer natural incentives to localize the supply chain significantly. However, the much larger volume of offshore wind development in the region offers potential for supply chain development in the region, including export opportunities for Sri Lanka.
- **Sri Lanka has no track record in offshore wind.** The country nonetheless has some capabilities in permitting and infrastructure development as well as operation and maintenance (O&M) in related sectors, such as onshore wind and onshore electrical infrastructure as well as offshore oil and gas exploration.
- **Port infrastructure needs to be properly assessed and upgraded.** The upgrades are required for the country's ports to suit the requirements of offshore wind installation operations and specialized vessels. Of Sri Lanka's four major ports, Colombo and Hambantota are suitable to support the installation of bottom-fixed offshore wind with only relatively minor upgrades. Trincomalee and Kankasenuthurai, however, would need major upgrades to be suitable. Capable ports could also allow the possibility of supplying the Indian offshore wind industry.
- **No dedicated offshore wind regulatory and institutional framework has been adopted.** The existing legal and regulatory system is primarily geared towards smaller scale, onshore renewable projects which does not provide the needed clarity and certainty especially with regard to planning and permitting.
- **The transmission system requires strengthening in consideration of the offshore wind capacities to be added.** Adding offshore wind farms of 500MW to 1GW each will have a significant impact on the transmission system. To be able to handle this ramp-up, there is need for proper planning and investments in grid infrastructure to provide the necessary upgrades.
- **Large CAPEX, insufficient, and high cost of domestic capital are challenges to an affordable cost of electricity from Sri Lanka's first offshore wind developments.** The cost of capital from Sri Lankan banks is quite high since interest rates on loans could run as high as 15 percent. Local banks will likely not be able to provide loans at the scale and with the tenor needed for offshore wind. International capital will need to finance projects and access to low-cost concessional finance will be essential to reduce the cost of energy of the first offshore wind projects.

6 ROADMAP AND RECOMMENDATIONS

The previous chapters have examined the current situation regarding offshore wind and its potential in Sri Lanka and presented the findings and major themes. This chapter aims to transform those findings into a concrete set of recommendations for the Government of Sri Lanka. Depending both on the extent to which these recommendations are implemented and market conditions, there are a range of growth outcomes possible for offshore wind. This roadmap considers two possible growth scenarios which represent a lower bound — the low growth scenario — and a higher bound — the high growth scenario. Finally, the recommendations and growth scenarios are combined with a time schedule, resulting in two roadmaps for the development of offshore wind in Sri Lanka.

6.1 RECOMMENDATIONS

Kick-starting an offshore wind industry can be done at different growth rates, but the overall development milestones and recommendations for Sri Lanka remain similar. The recommendations mainly focus on actions to be taken on the short-term, but some can span over the entire timeframe up to 2050. Most of these recommendations are equally valid for the low growth or high growth scenarios.

Vision and Volume Targets

1. **Sri Lankan Sustainable Energy Authority (SLSEA) and Ceylon Electricity Board (CEB) should integrate offshore wind into the long-term generation expansion plan (LTGEP).** A holistic plan, supported by energy system modeling should consider the characteristics of offshore wind and its potential contribution to the country's decarbonization goals.
2. **SLSEA should establish a long-term vision for offshore wind including installation targets.** Including both shorter (i.e., 2030) and longer (i.e., 2050) targets helps investors to plan and gives confidence in the market opportunity. The vision should be informed by the LTGEP and economic analysis. Longer-term opportunities such as floating wind and green hydrogen should also be included in the vision.
3. **One or two 500MW pathfinder project(s) should be considered by SLSEA.** This capacity could be commissioned around 2030 and would help to overcome barriers and risks for future capacity additions, enabling subsequent cost reductions.

Regulatory and Policy Framework

4. **SLSEA in collaboration with other authorities such as Petroleum Development Authority of Sri Lanka (PDASL) and Marine Environmental Protection Authority (MEPA), should lead integrated spatial planning to identify and assess the preferred locations for future offshore wind projects.** The spatial planning should include stakeholder engagement and strategic baseline studies to ensure well-informed site selection. This work can be supported by subsequent technical assistance from development partners.
5. **Sri Lanka should follow a government-led approach to planning and procuring the pathfinder project(s).** The SLSEA should plan this approach, discuss it with industry and other stakeholders, then publish it in the Sri Lanka Gazette. The process should be competitive, fair, and transparent, taking lessons from international experiences and incorporating them with local norms.
6. **SLSEA should carry out a regulatory gap analysis and identify any required amendments or new regulations to deliver the government-led procurement model.** Many elements of the framework can be adjusted to suit the requirements of offshore wind but others, such as the provision of seabed leases/concessions may require new legislation.
7. **The Central Environmental Authority (CEA), in collaboration with SLSEA, should develop and publish detailed guidance on the permitting process.** This should include a list of all the permits, authorities, and timelines to be considered. This should also include the important environmental and social impact assessment (ESIA) process following good international industry practice (GIIP).

Financial and Economic

8. **SLSEA, with support from development partners, should investigate the use of derisking mechanisms, including guarantees, and opportunities to mobilize low-cost concessional finance.** The objective is to ensure the pathfinder project(s) risk is sufficiently mitigated to encourage investors and to reduce the cost of financing. This will help to reduce the cost of electricity and ensure the participation of competent, experienced developers, which will increase the chance of successful delivery.
9. **The CEB should establish a long-term, bankable, power purchase agreement (PPA).** This should take into account the specificities of offshore wind, fairly allocating risk between off-taker and developer, and ideally addressing exchange rate risk, repatriation of profits, and curtailment payments. The PPA must be considered bankable for projects to obtain debt financing.
10. **SLSEA and CEB should also consider the feasibility and potential benefits of renewable energy support schemes.** This would include any additional mechanisms needed to reduce the PPA price to an acceptable, affordable level.

Health and Safety (H&S)

11. **The Government should introduce H&S requirements in alignment with industry best-practice standards.** This should adopt international standards with a long track-record, which ensures safe procedures during installation and operation.

Grid and Port Infrastructure

12. **The Sri Lanka Ports Authority (SLPA) should assess port requirements and options for upgrading ports to support the installation of the pathfinder and subsequent projects.** This should consider the feasibility and merits for upgrading Sri Lanka's ports and whether there are more economical options.
13. **Assuming a local port should be upgraded, SLPA should undertake works to improve the capabilities of the port of Colombo and/or Hambantota.** The works should be strategic, considering opportunities to supply/service projects being developed in India as well as domestically.
14. **SLPA should assess and upgrade smaller local ports to use in the O&M phase** in order to enhance local job creation as well as ensure a reliable, safe, and lasting operation of the wind farms.
15. **CEB should include offshore wind in the next iteration of the long-term transmission development plan (LTTDP).** This should be based on the LTGEP, and the targets and timelines set by SLSEA.
16. **CEB should clarify which entity is responsible for constructing and operating the export system between an offshore wind farm and the onshore transmission grid.** It is recommended that this should be the responsibility of the developer, though CEB could be best placed to lead the onshore work.
17. **CEB should construct strategic transmission reinforcements.** Given the scale and long development times of offshore wind projects, these sizable reinforcements should be planned and implemented well in advance of projects being commissioned. They can be delivered strategically to avoid a less-efficient project-by-project approach.
18. **The Ministry of Power and CEB should continue to explore the electrical interconnection link with India.** This could enable the partial or full sale of offshore wind generated power to consumers or markets in the region, as well as helping to balance the local grid and facilitate the integration of variable renewable energy.
19. **As part of a long-term decarbonization plan, SLSEA and PDASL should explore the potential to produce green hydrogen and ammonia.** It is unlikely to be economically viable in the shorter term but, in the absence of an interconnector with India, this could become a critical part of the Sri Lankan energy system. Alternatively, cheaper sources of electricity could be used to produce green hydrogen, and offshore wind could be used to supply the grid.

Supply Chain

20. **SLSEA and the Sri Lanka Ports Authority (SLPA) should consider the merits of incentives to support industry growth and local supply chain capability**. This could, for example, include tax exemptions/reductions, availability of reduced rate land/property within port areas, or access to lower-cost finance.
21. **SLSEA and relevant Government agencies should map local supply chain capabilities.** This should identify local firms with any capability or likely future capability to supply or service offshore wind projects.
22. **SLSEA should consider establishing strategic regional partnerships with other offshore wind markets.** Suppliers in India, China, and Vietnam for example, could be an alternative to overcome domestic supply chain constraints and to both draw on regional skills and help develop them domestically.

6.2 ROADMAPS

FIGURE 6.1: LOW GROWTH SCENARIO FOR OFFSHORE WIND DEVELOPMENT IN SRI LANKA.

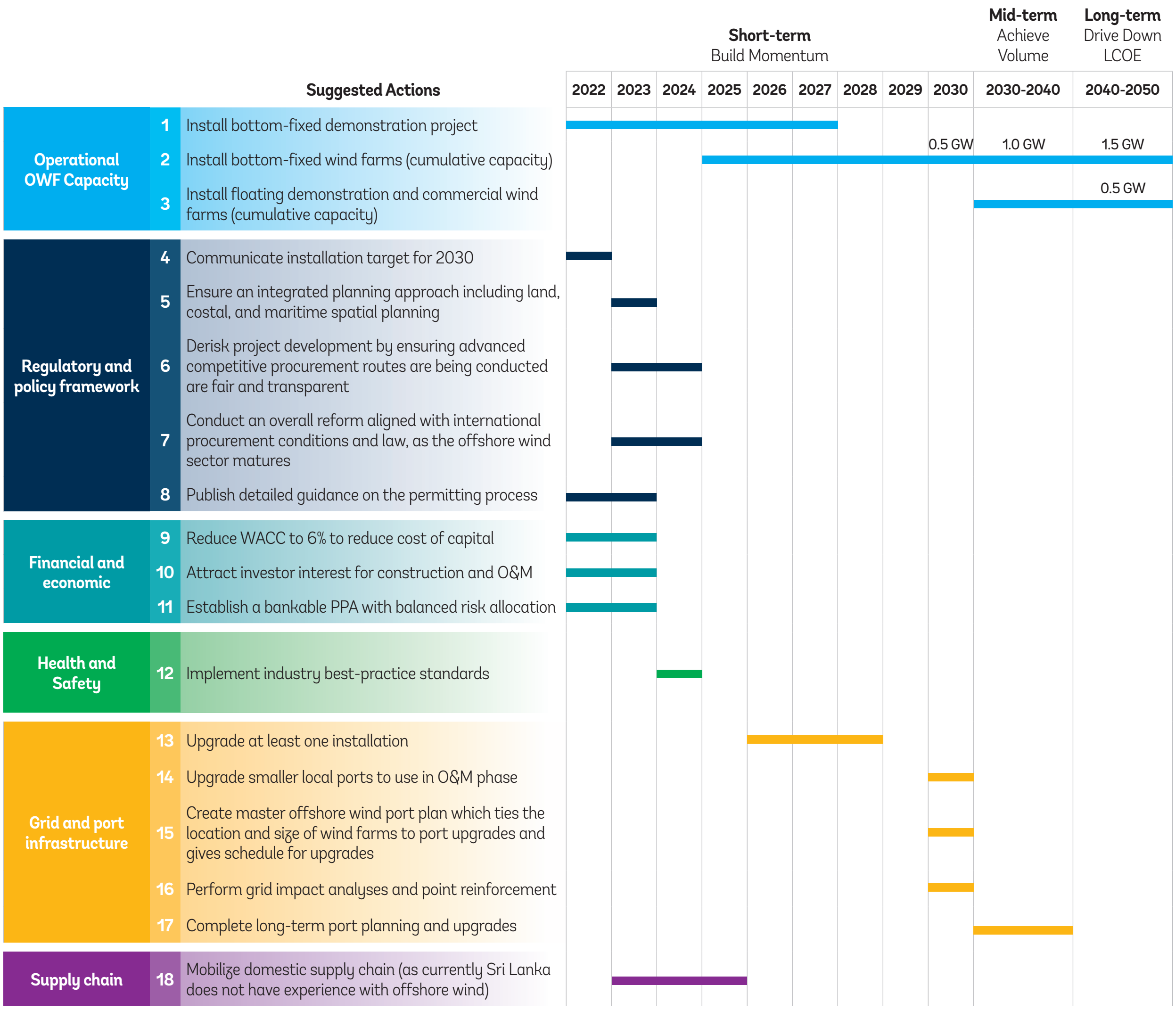
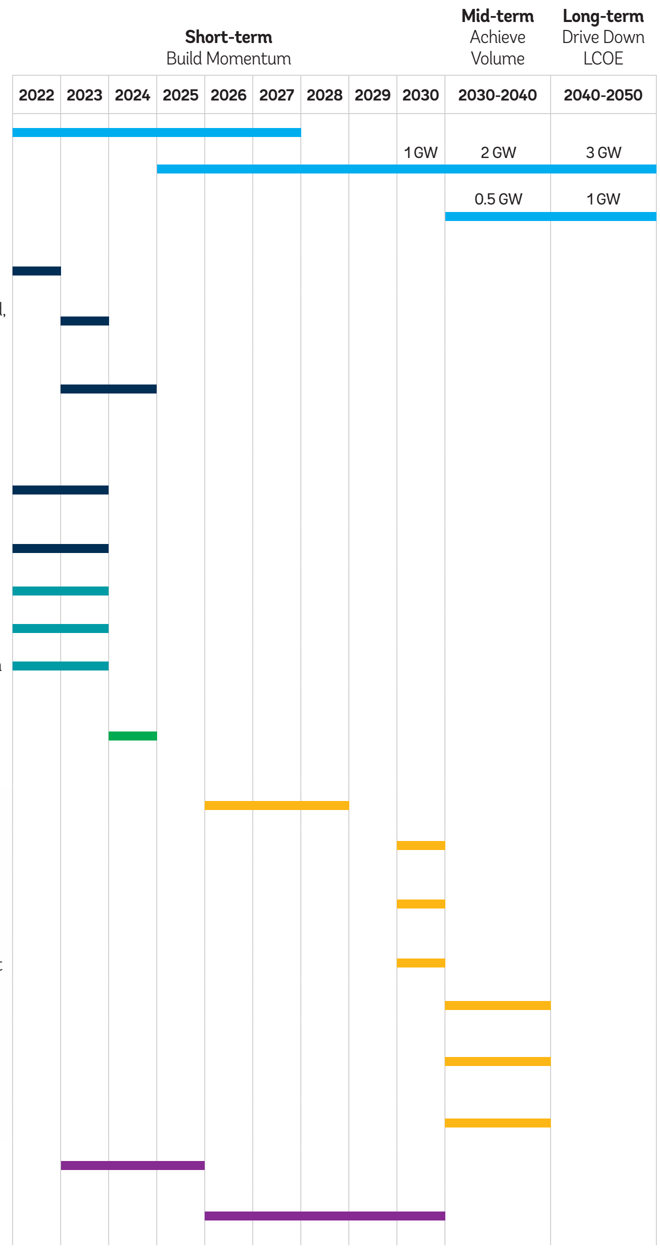


FIGURE 6.2: HIGH GROWTH SCENARIO FOR OFFSHORE WIND DEVELOPMENT IN SRI LANKA.

		Suggested Actions
Operational OWF Capacity	1	Install bottom-fixed demonstration project
	2	Install bottom-fixed wind farms (cumulative capacity)
	3	Install floating demonstration and commercial wind farms (cumulative capacity)
Regulatory and policy framework	4	Communicate installation target for 2030
	5	Ensure an integrated planning approach including land, costal, and maritime spatial planning
	6	Derisk project development by ensuring advanced competitive procurement routes common to large scale OWF projects are being conducted are fair and transparent
	7	Conduct an overall reform aligned with international procurement conditions and law, as the offshore wind sector matures
	8	Publish detailed guidance on the permitting process
Financial and economic	9	Reduce WACC to 6% to reduce cost of capital
	10	Attract investor interest for construction and O&M
	11	Establish a bankable PPA with balanced risk allocation
Health and Safety	12	Implement industry best-practice standards
Grid and port infrastructure	13	Upgrade at least one installation port
	14	Upgrade smaller local ports to use in O&M phase
	15	Create master offshore wind port plan which ties the location and size of wind farms to port upgrades and gives schedule for upgrades
	16	Perform grid impact analyses and point reinforcement
	17	Complete long-term port planning and upgrades
	18	Perform long-term grid planning and necessary reinforcement, including possible interconnection link with India
	19	Explore PtX plant for storing excess electricity
Supply chain	20	Mobilize domestic supply chain
	21	Develop regional partnerships to fast track domestic supply chain (e.g., with China, Vietnam, India)



SUPPORTING INFORMATION

7 ASSESSMENT OF OFFSHORE WIND AREAS

Sri Lanka has good conditions for offshore wind and previous work [1] by the World Bank estimated Sri Lanka has 91GW of technical potential. The previous spatial assessment was limited in that it only considers wind speed and water depth as the main parameters defining the resource potential. The screening for offshore potential performed under this roadmap builds on the previous work and includes an assessment of seabed conditions, wind resource, and environmental and social constraints. With these three topics mapped, the overall locational potential can be estimated.

7.1 SEABED CONDITIONS

This section provides a preliminary assessment of the seabed, geology, and seismic conditions offshore Sri Lanka. Geology and seismic conditions are included in the screening as these factors impact foundations and the structural integrity of OWFs. Extreme or harsh conditions may result in exclusion of some areas.

It shall be noted that the data presented is not of a quality suitable for design and shall be considered as for information only. More detailed hydrographic, geophysical, and geotechnical surveys and results are required during the development of offshore windfarms.

7.1.1 Data

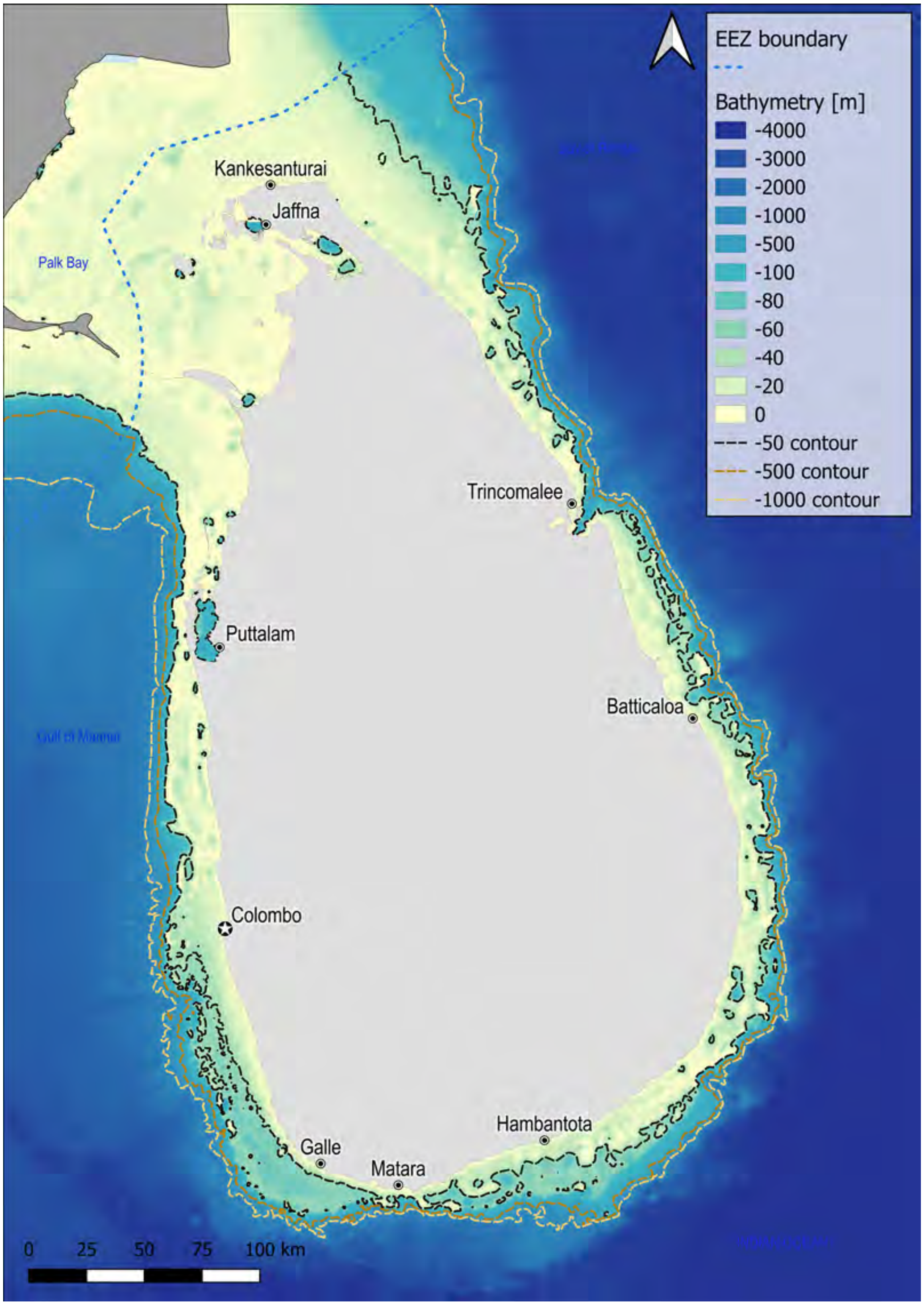
The main available data that have been used as basis for the screening is:

- Bathymetry — grid from GEBCO (~450m resolution)
- Morphology — data from ESRI
- Faults — data provided by PDASL

7.1.2 Morphology

The bathymetry offshore Sri Lanka shows that relatively shallow waters are found to the north between Sri Lanka and India, whereas areas of shallow waters are more limited in the south (Figure 7.1).

FIGURE 7.1: BATHYMETRY OFFSHORE SRI LANKA [25].

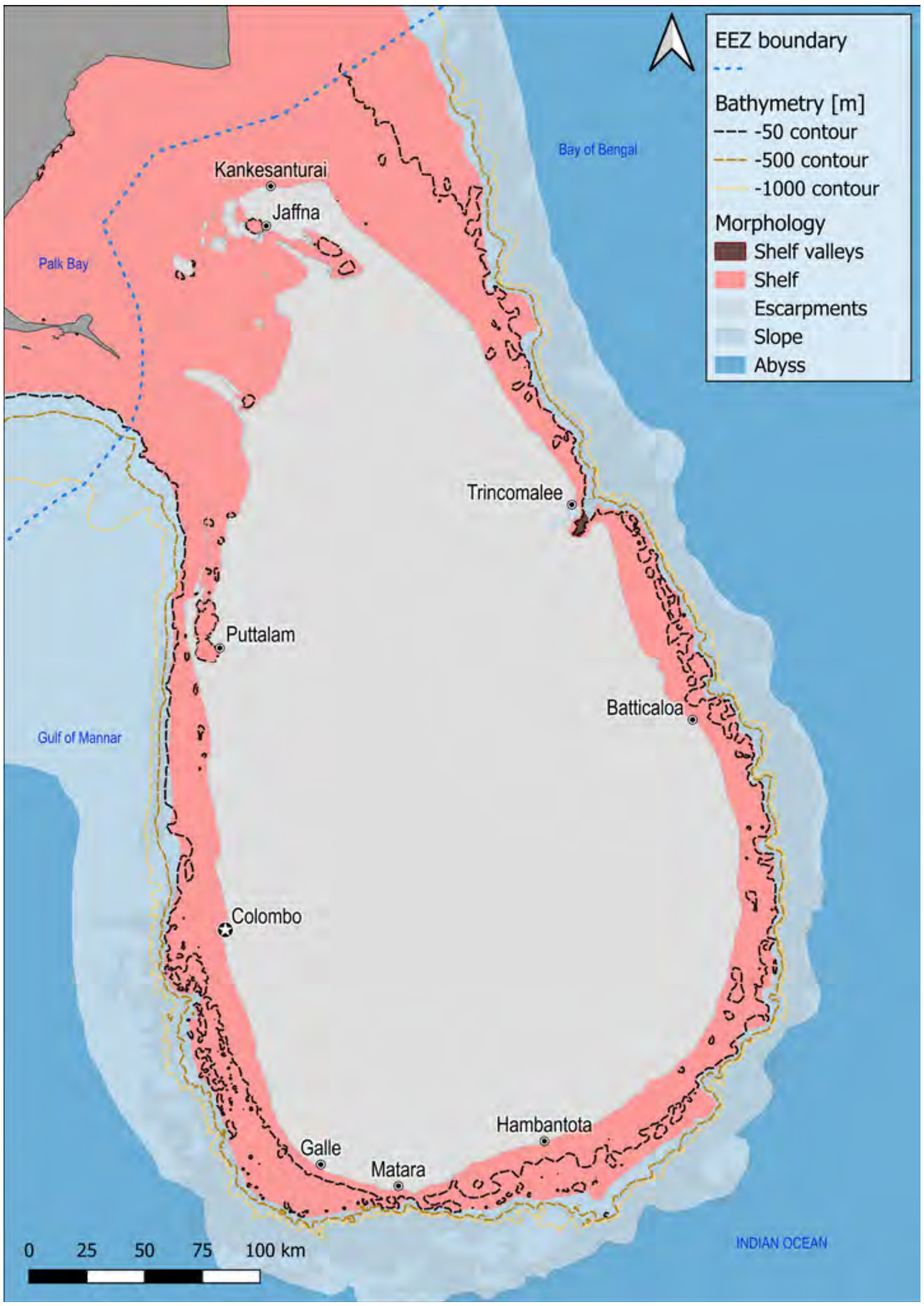


Source: GEBCO

Waters shallower than -50m are typically suitable for fixed wind turbine generators (WTGs). Water depths beyond the -500m contour line are less economical for floating foundations.

Large-scale morphological seabed features (e.g., shelf valleys and escarpments), are shown on Figure 7.2. Escarpments related to steep slopes at the transition from shelf to abyss are dominant along the entire coastline except in the northwestern area. A prominent shelf valley is found at Trincomalee on the northeast coast.

FIGURE 7.2: MORPHOLOGY OFFSHORE SRI LANKA SHOWING GENERAL LARGE-SCALE FEATURES [26].



The northwestern coast is shielded by the Indian subcontinent and preserves longshore sediments that arrive with the southwest monsoon period. Hence, many islands and sediment barriers are found along the coast [27]. Along the northwestern, northern, and eastern coasts net accumulation is taking place, meaning that the coastlines are expanding.

On the contrary, along the southwestern and northeastern coasts sea currents caused by the southwest monsoon leads to net erosion, meaning that the coastlines are retreating [28, 27].

7.1.3 Geology

Geologically, 90 percent of Sri Lanka is made up of Precambrian crystalline rocks and have been divided into four complexes, the Wanni Complex, the Highland Complex, the Kadugannawa Complex, and the Vijayan Complex (Figure 7.3). The relative levels of land and sea have remained practically the same since Miocene times. However, minor post-Miocene oscillations in sea level have led to the deposition of Miocene to Quaternary formations and changes in the coastal regions [28].

Three main sedimentary basins are found offshore Sri Lanka: the Cauvery Basin, the Mannar Basin, and the Southern Basin (Lanka Basin) (Figure 7.3). Cauvery and Mannar basins are located on a rift margin between India and Sri Lanka, while the Southern Basin is a passive margin. Whereas large parts of the Southern Basin are underlain by oceanic crust, there is no evidence to support that there is oceanic crust development in the Cauvery or Mannar basins. Rocks of the Wanni Complex comprise the basement in the Cauvery Basin as well as in the northern part of the Mannar Basin. In the southern part of the Mannar Basin and in parts of the Southern Basin the basement is comprised of rocks from the Highland Complex. To the east, the Vijayan Complex extends out in the Southern Basin.

Within the Mannar and Cauvery basins, major faults which are cutting the basement have been interpreted based on seismic exploration surveys (Figure 7.4).

FIGURE 7.3: SIMPLIFIED GEOLOGICAL MAP OF SRI LANKA PRESENTING THE SUBDIVISION OF THE CRUSTAL BASEMENT: THE WANNI COMPLEX, THE HIGHLAND COMPLEX, THE KADUGANNAWA COMPLEX (GREEN), AND THE VIJAYAN COMPLEX AS WELL AS THE THREE SEDIMENTARY BASINS: THE CAUVERY BASIN, THE MANNAR BASIN, AND THE SOUTHERN BASIN (LANKA BASIN) [29].

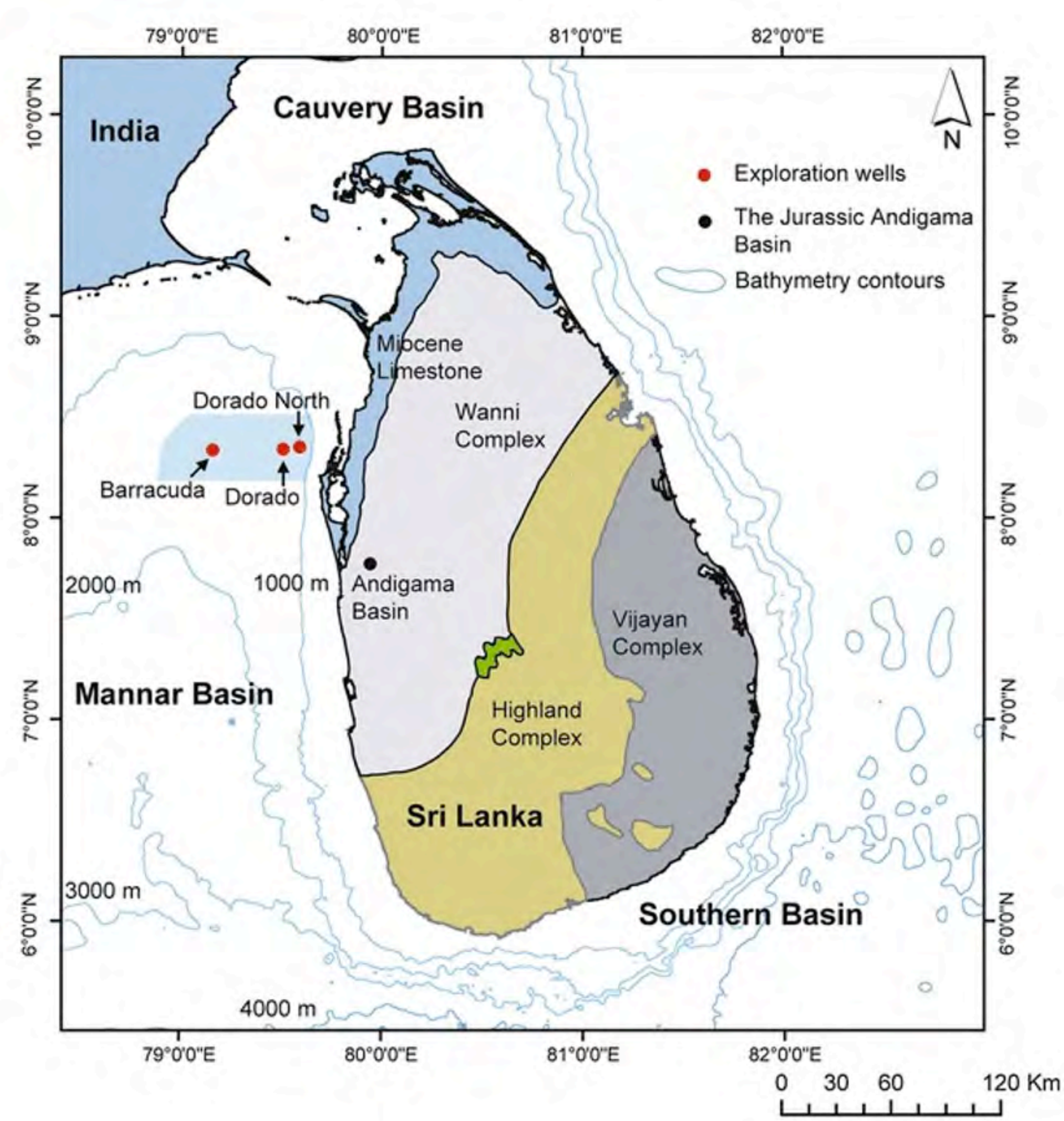
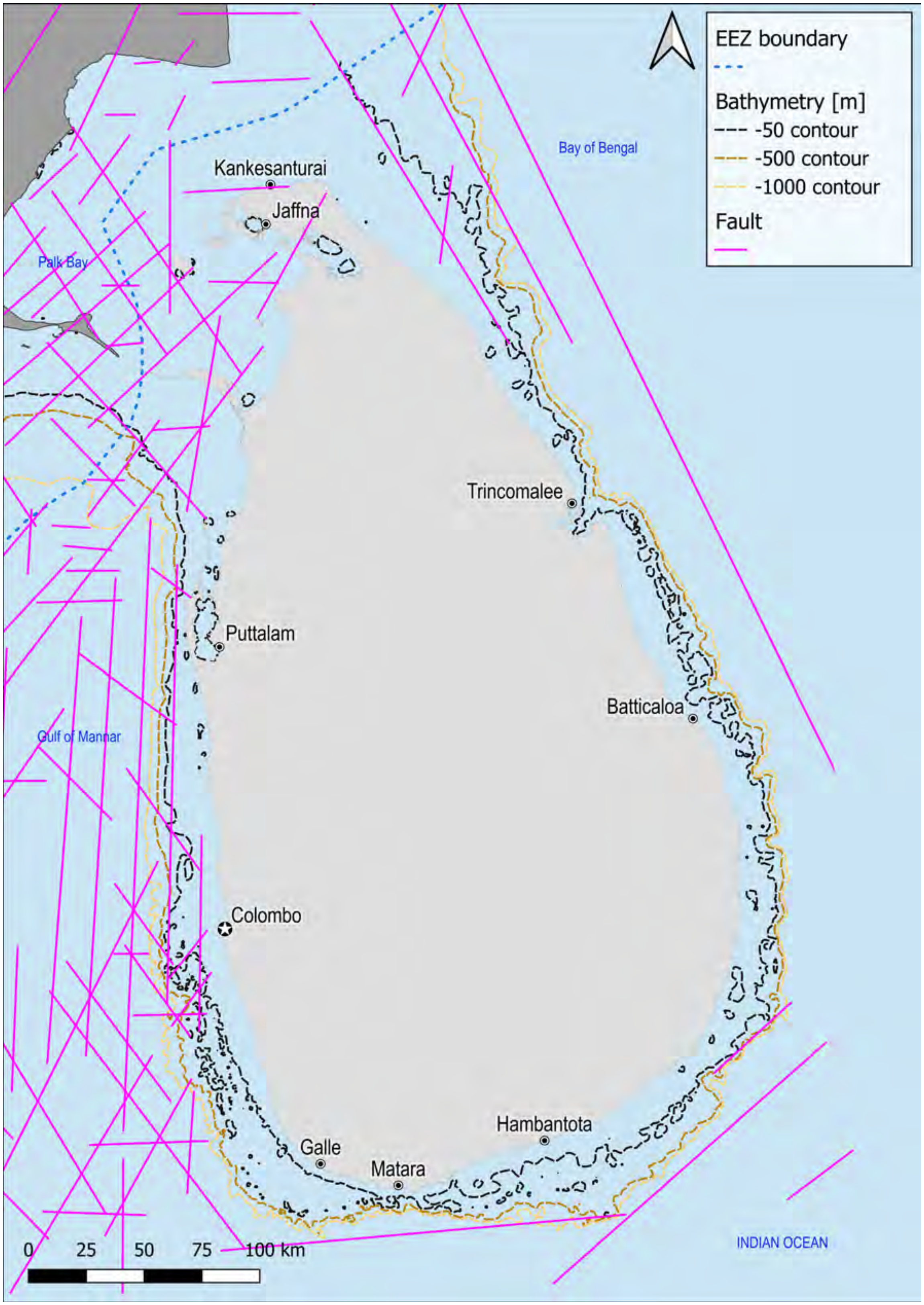


FIGURE 7.4: FAULT LINES INTERPRETED BASED ON SEISMIC EXPLORATION SURVEYS [30] [31].

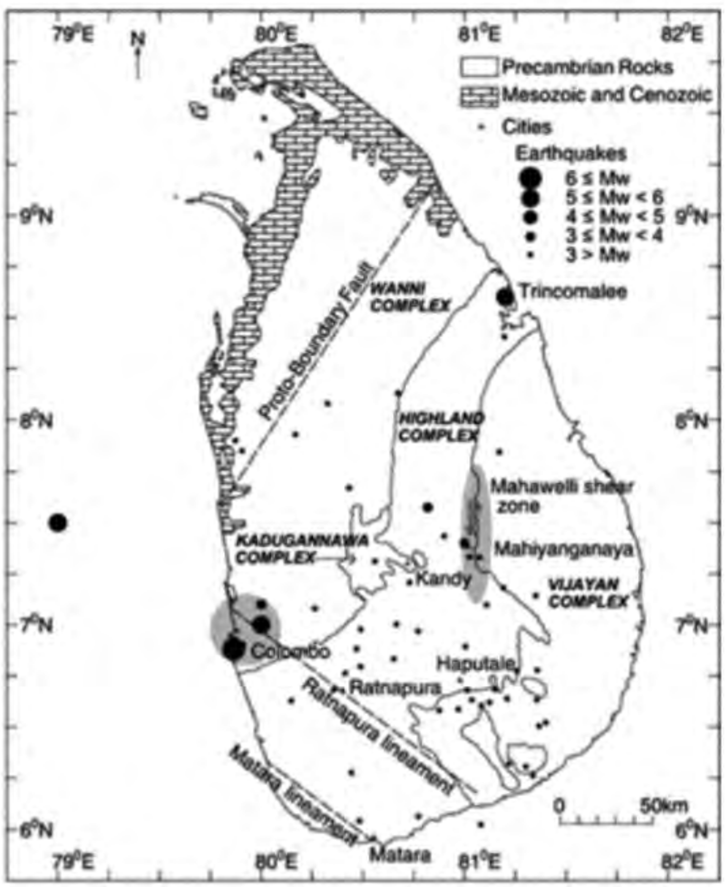


7.1.4 Seismicity

Sri Lanka is considered an aseismic region located well away from major plate tectonic boundaries. The risk of an earthquake hazard is classified as very low, meaning that there is less than two percent risk of a potentially damaging earthquake in the country within the next 50 years. Nevertheless, a considerable number of small to medium magnitude intra-plate seismic events has been recorded in and especially around Sri Lanka. Most of these events were microevents which may be caused due to local tectonics or human activity [30, 32]. However, conversion of historic records indicates that earthquakes with magnitude above five have occurred at Trincomalee and Colombo in 1882 and 1615 respectively (Figure 7.5) [30].

Furthermore, a large area of diffuse seismicity located south-southeast of Sri Lanka (northern part of the Ninetyeast Ridge), could be a dominant source of strong shallow intraplate earthquakes, and could render direct threats of striking large-magnitude events in close proximity to the country [31].

FIGURE 7.5: HISTORICAL EARTHQUAKES FROM 1615 TO 2004 [30].



Despite the low to moderate risk for earthquakes, the risk for a tsunami hazard is classified as medium, meaning that there is more than a ten percent risk of a potentially damaging tsunami occurring within the next 50 years. Based on this information, the impact of tsunami should be considered in different phases of potential offshore projects for any activities located near the coast.

Moreover, it shall be noted that low amplitude a tsunami waves (length ~ 100km, height < 1 m) have been associated with significantly more scour than shorter solitary waves [33].

7.1.5 Findings

The assessment shows that in general, there are no major seabed obstacles or challenges for construction and operation of offshore wind farms.

There is a significant area with water depth below 50m, which will be suitable for fixed bottom WTGs. Further, there is a large area with water depths of 50-500m, which is the limit currently considered for floating foundations. Finally, if looking further into the future and a possible range of water depths up to 1,000m for floating foundations, the potential for offshore wind locations will expand even further.

Earthquakes are not considered a major concern. However, development of sites close to shore must take into consideration tsunami incidents and especially the potential scour related to low amplitude tsunami waves.

7.2 Wind Resource

7.2.1 Wind Resource

The wind resource in different areas in Sri Lankan waters has been evaluated to identify and map the potential for offshore wind development in Sri Lanka. For offshore sites, there are no local speed-ups from the terrain, and thus for this screening exercise, it is considered sufficient to use mesoscale data as an input. The Global Wind Atlas (GWA) is an appropriate mesoscale data set that can be used for such a screening exercise and was used as basis for the analysis in this roadmap.

Currently, 7m/s is considered the lowest feasible average wind speed for economically viable offshore projects. As can be seen in Figure 7.7, Sri Lanka has moderate wind speeds which are relatively evenly distributed around two main areas. North of Puttalam there is a small pocket of 9-9.5m/s wind, which decreases gently and consistently to the east and west. Similarly, there is a pocket of >9.5m/s speeds east of Matara, which decreases gently in a concentric pattern. In addition to these areas, there is a very large area in the Bay of Bengal with 7-7.5m/s.

Finally, it must be noted that Sri Lanka is prone to high-wind incidents (tropical cyclones). Figure 7.6 presents the storm incident and path based on up-to-date data collected by NOAA from 1841 to 2021. The storms categories are classified according to Saffir Simpson hurricane wind scale[13] as showen in Table 7.1. The corresponding wind speeds are for one-minute maximum sustained winds.

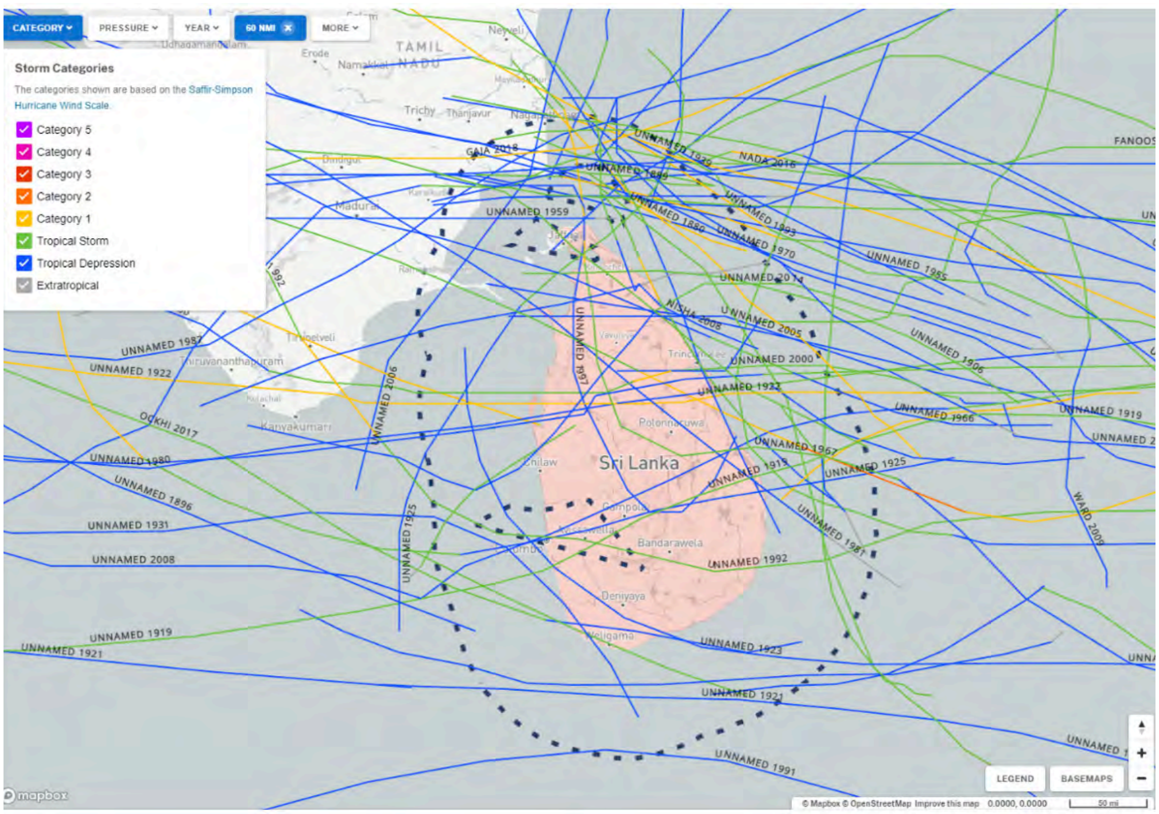
13 H. S. Saffir, "Hurricane Wind and Storm Surge" The Military Engineer, Vol. 423, 1973, pp.4-5.

TABLE 7.1: SAFFIR-SIMPSON HURRICANE WIND SCALE.

Saffir—Simpson Scale[14]	
Category	**Wind Speeds [m/s]**
Five	≥ 70m/s
Four	58–70m/s
Three	50–58m/s
Two	43–49m/s
One	33–42m/s

As observed in Figure 7.6, most of the storm categories in Sri Lanka and vicinity are tropical depressions (up to 17m/s) and tropical storms (up to 32.5m/s), respectively blue and green color. However, there are also category one and two storms, which corresponds to wind speeds between 33-49m/s.

FIGURE 7.6: STORM INCIDENTS AROUND SRI LANKA FROM YEARS 1841-2020.



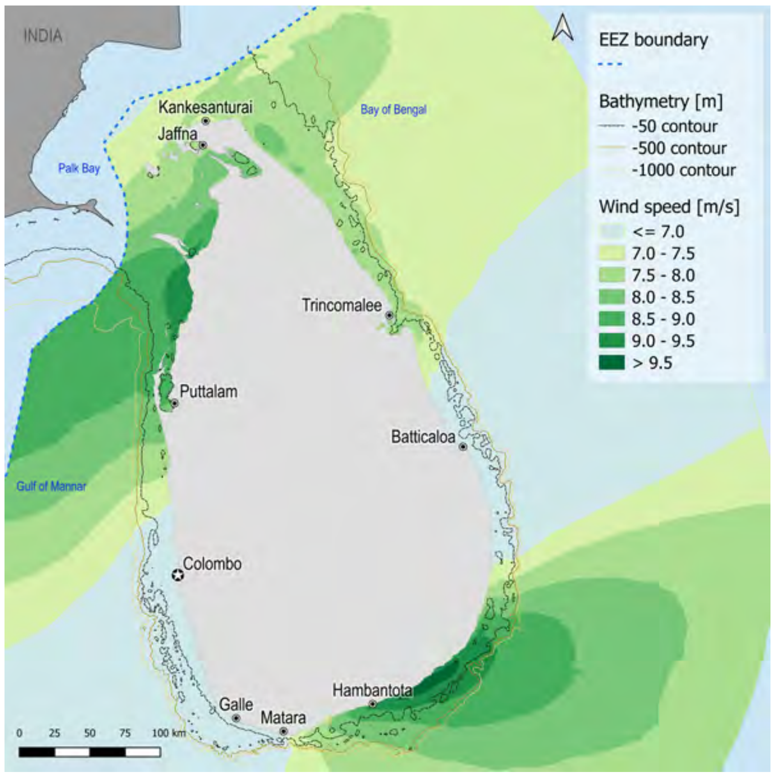
Source: US National Ocean and Atmospheric Administration (NOAA).

14 https://www.nhc.noaa.gov/aboutsshws.php

7.2.2 WTG Type

Most offshore WTGs currently on the market are designed for high average wind speeds of up to 10m/s and, while technically suitable for less energetic sites, they are not optimized for moderate (up to 8.5m/s) or low (up to 7.5m/s) wind speeds. As the offshore wind sector matures, and as the medium-to-low wind speed sites become increasingly viable to develop, OEMs are expected to develop lower wind speed WTG types. In turn, with this market-driven development, development of these WTGs will improve LCOE of projects.

FIGURE 7.7: AREAS WITH MEAN WIND SPEED HIGHER THAN 7.0M/S AT 150M BASED ON GLOBAL WIND ATLAS[15] [19].



Source data: Global Wind Atlas

Given the overall wind resource in Sri Lanka, an estimation of energy outputs has been based on WTGs with relatively larger rotor diameters and lower rated power, resulting in a lower power density (the power divided by the swept area of the WTG) which is generally favorable for lower wind resources. This is based on the current available information on WTG technology (such as power curves) suitable for different wind regimes. However, the possibility for high-wind incidents or tropical cyclones must also be taken into consideration when selecting a specific WTG for a project in Sri Lanka. It is therefore recommended to apply site specific approval (i.e., a certification of a given WTG for a specific site and its related conditions). It is expected that the O&M of the wind farms consider the incidence of storms and the limits of the WTGs, and a detailed site assessment is recommended to evaluate site conditions and extremes for offshore wind development.

15 Data obtained from the Global Wind Atlas 3.0, a free, web-based application developed, owned, and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 was released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info

7.3 TECHNICAL, ENVIRONMENTAL, AND SOCIAL CONSTRAINTS

Offshore wind can be a major element in addressing the challenges of climate change and can potentially create both economic and environmental benefits for generations to come. However, multiple use of ocean resources by many stakeholders requires careful consideration and coordination.

This section discusses the technical constraints, and environmental and social sensitivities that may influence the future development of Sri Lanka's offshore wind market. The analysis includes a high-level assessment and mapping of potential environmental, social, and technical constraints in relation to offshore wind development in Sri Lanka. The assessment includes recommendations on how to incorporate and plan for environmental and social constraints. It shall be noted that WBG and IFC performance standards should be used as the guiding principles for assessment of environmental and social constraints, specifically as these forms the basis for international financing support.

7.3.1 Method

The constraint mapping has been conducted through a review of scientific literature and existing datasets, as well as experience from established offshore wind projects and markets. As far as possible the environmental, social, and technical constraints have been mapped spatially.

A study on Sri Lanka's offshore and coastal biodiversity was undertaken by the Biodiversity Consultancy and this is provided in Appendix A. This study identifies potential biodiversity sensitivities which could be adversely impacted by offshore wind development. The high sensitivity of some areas means that it is highly unlikely that offshore wind projects could be developed to meet good international industry practices (GIIP) or international lenders' E&S requirements — therefore, these zones have been excluded from further consideration. Other areas have high E&S sensitivities, but it may be possible to sustainably develop projects in these areas, however the restrictions have been noted. These two classifications of zones are defined as:

- **Exclusion zones** comprised of areas of the highest environmental and social sensitivities and are considered as "no-go" areas to exclude from offshore wind site selection.
- **Restriction zones** are high-risk areas requiring further assessment of environmental and social risks through marine spatial planning (MSP), site selection, and/or environmental and social impact assessment (ESIA).

Some stretches of Sri Lanka's coast have fewer constraints and include the areas between Jaffna and Trincomalee, as well as between Puttalam and Colombo. Although these areas have fewer exclusion and restriction zones, they may contain sensitivities that have not been identified in this initial assessment.

Gathering stakeholder input should be an ongoing process, particularly for the protection of environmental resources and social sensitivities. Multiple stakeholders will include environmental groups, non-governmental organizations, business interests, offshore wind industry representatives, and local communities.

7.3.2 Results

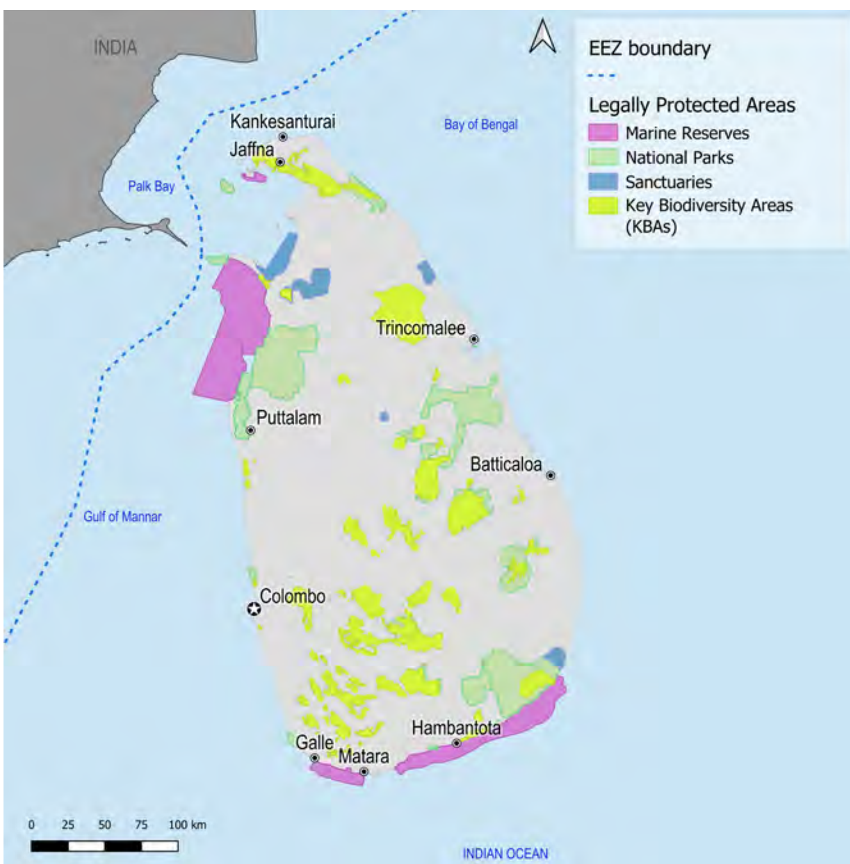
Legally Protected Areas (LPAs) and Internationally Recognized Areas (IRAs)

Legally Protected Areas (LPAs) and Internationally Recognised Areas (IRAs) represent high-value areas designated for various biodiversity conservation objectives, and some should be excluded from consideration for offshore wind development because of this. The LPA system in Sri Lanka is aligned with the International Union for the Conservation of Nature management categories and include Nature Reserves, National Parks, and Sanctuaries. The IRAs include Ramsar sites, Key Biodiversity Areas (KBAs) including Important Bird Areas (IBAs), Ecologically or Biologically Significant Areas (EBSAs), and Important Marine Mammal Areas (IMMAs).

The Bundala Biosphere Reserve is Sri Lanka's only coastal UNESCO-MAB Biosphere Reserve and is located along the south coast, around Hambantota. This is an area of high biodiversity value, including important wetland habitat. This area is included as an exclusion zone.

The designated sites with marine components more likely to be impacted by offshore wind projects are Marine National Parks, Nature Reserves, Sanctuaries, and KBAs which include Important Bird Areas (IBAs) and Ramsar sites. It is recommended that these areas, shown in Figure 7.8 are excluded from offshore wind development and are thus included in the exclusion zone layer.

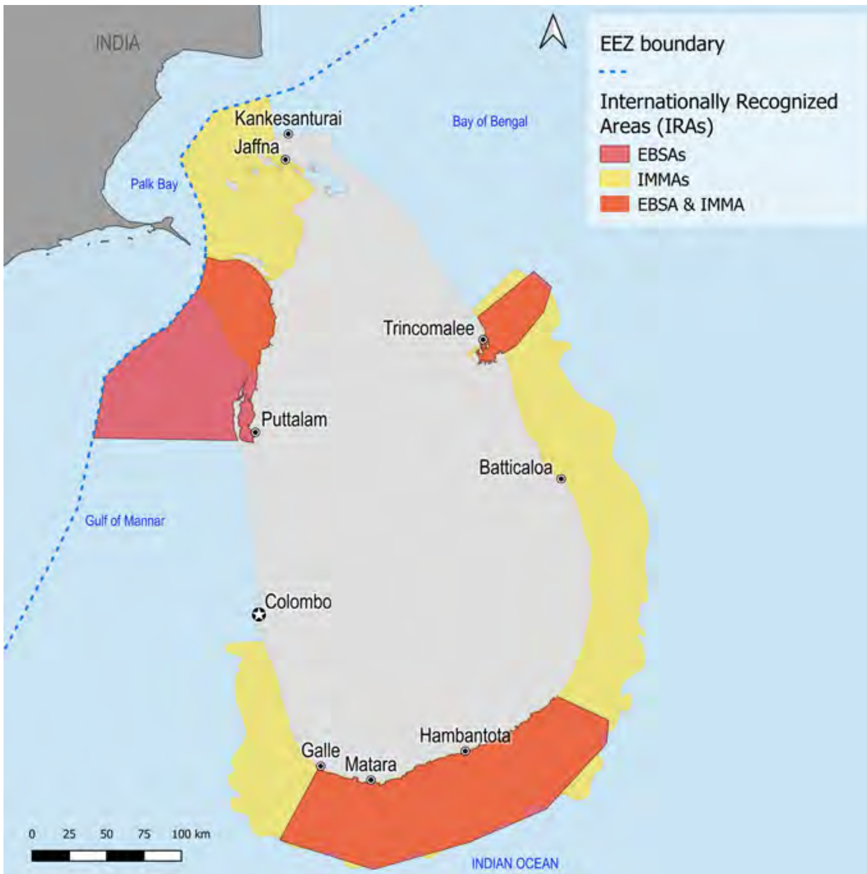
FIGURE 7.8: PROTECTED AREAS (PAS) IN SRI LANKA WITH MARINE COMPONENTS.



Source: See Appendix A

EBSAs and IMMAs may be feasible for development if they are carefully managed and development activities are coordinated to avoid key sensitive periods for biodiversity. These sites are therefore included in the restriction zone layer and shown in Figure 7.9. Options for Sri Lanka include identifying those areas with potential for multi-use for offshore wind farms and those that are incompatible. The best option is to avoid offshore wind development in designated sites, followed by technical options for mitigating potential impacts. This roadmap shows that Sri Lanka only requires a fraction of the offshore area to meet the high growth scenario — even taking into account restrictions.

FIGURE 7.9: INTERNATIONALLY RECOGNISED AREAS (IRA) IN SRI LANKA WITH MARINE COMPONENTS.



Source: See Appendix A

7.3.3 Threatened Marine Species

Threatened and range-restricted species are the focus of criteria one and two for the determination of critical habitat, as defined by IFC Performance Standard 6 and therefore represent priority biodiversity values. Some threatened and range-restricted marine species in Sri Lanka are sensitive to survey and construction activities. These species are in general those that are particularly sensitive to underwater noise, vibration, or smothering or loss of seabed habitat.

Developers should consider the likely presence of sea turtles, marine mammals, threatened fish species, and sharks. Some endangered and critically endangered species, such as five species of sea turtles, fish, sharks, and rays are found in Sri Lanka. In addition, Sri Lanka supports a high diversity of marine mammals, with 27 recorded species. Of these, six are assessed as globally threatened species including the Blue Whale (Balaenoptera musculus) and dugong (Dugong dugong) which have been recorded in the Gulf of Mannar, the waters between Galle and Mannar, and in Trincomalee Canyon (northeast coast of Sri Lanka).

Offshore wind development poses several risks to cetaceans, dugongs, and sea turtle populations, of which disturbance of nesting beaches for sea turtles, destruction of seagrass beds (foraging grounds for dugongs) and, underwater noise are possibly of most concern.

There are five threatened species of marine turtles with global ranges that overlap with Sri Lanka EEZ. Although turtle nesting beaches are distributed across the entire coastline, except in Puttalam and Gampaha districts, the primary nesting beaches can be found on the west, south, and the southeastern coasts. Galle and Hambantota districts in particular harbour the most used nesting beaches. Marine turtle nesting beaches feature in the designations of LPAs and EBSAs. However, there are also many important nesting sites along the west coast which are not covered by these designations. It is recommended that nesting beaches for marine turtles, plus a 5km buffer are excluded for offshore wind development. These areas are included in the exclusion zone layer (Figure 7.10).

FIGURE 7.10: NESTING BEACHES FOR TURTLES WITH 5KM BUFFER ZONE.

Source: See Appendix A

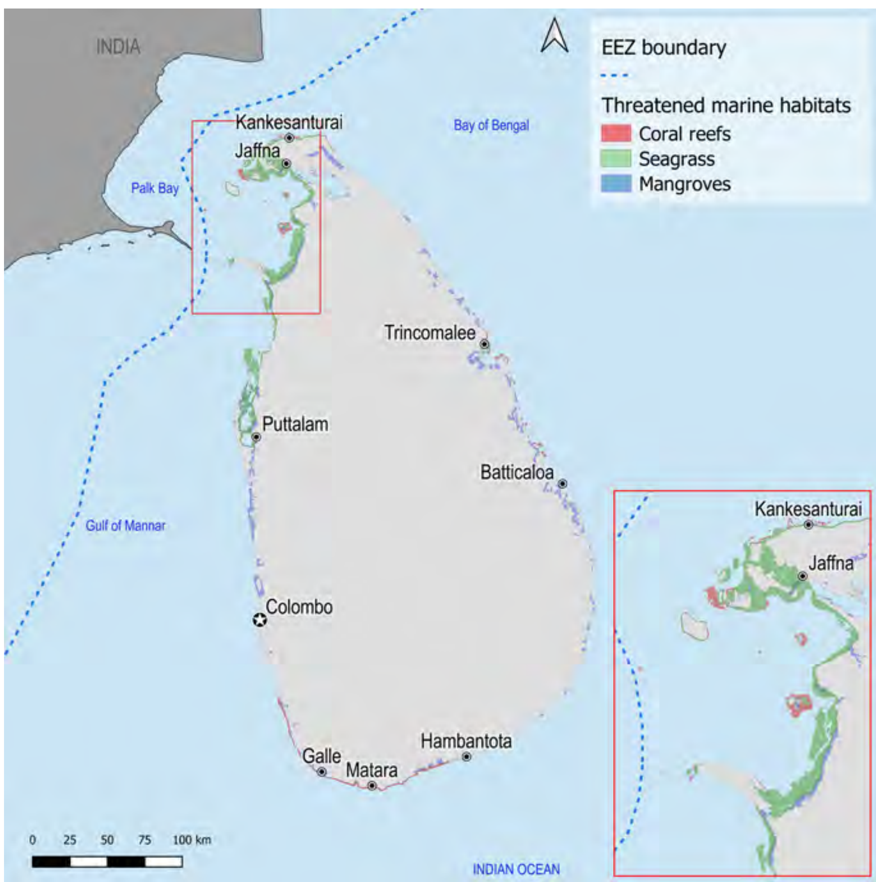
7.3.4 Threatened Natural Habitats

Sri Lanka has no official list of threatened natural habitats. However, several ecosystems are highly important both ecologically and economically for the country. This includes pearl mussel beds, seagrass beds, mangroves, coral reefs, and coastal sand dunes. The modelled distribution of seagrass beds, mangroves, and coral reefs are included within the exclusion zone layer. The most important areas for pearl beds fall within the Gulf of Mannar EBSA, which is therefore included in the restriction zone.

The majority of important habitats are clustered in the intertidal zone within protected areas in at the northwestern coast from Puttalam Lagoon in the Gulf of Mannar to the northern end of Palk Bay. Coral reef hotspots include Jafna Peninsula, the Gulf of Mannar, Negombo, Hikkaduwa, Galle, Matara, Basses, Passekudah, and Trincomalee.

Options for Sri Lanka include careful management of the wind farms and reducing physical damage of threatened habitats like coral reefs or seagrass beds by optimizing the positions of the WTGs, considerations of floating foundations, restoration, and management of compensatory biodiversity refuges.

FIGURE 7.11: DISTRIBUTION OF THREATENED MARINE HABITATS (CORAL REEFS, SEAGRASS, AND MANGROVES) IN SRI LANKA.



Source: See Appendix A

7.3.5 Migratory Birds and Bats

Birds are included within the designations of Ramsar sites and Important Bird Areas (IBAs). Usually, it is recommended that all IBAs and Ramsar sites are treated as exclusion zones for offshore wind development. Sri Lanka, however, has no marine areas IBAs, but there are several coastal IBAs that include marine bird species in their designation. These coastal IBAs have been included as exclusion zones.

The designated bird areas are likely to include most seabird nesting colonies and non-breeding aggregations of international importance. Among these is Sand Island III west of Mannar Island. This is the only known breeding colony in Sri Lanka for many seabirds and has therefore been included in the exclusion zone. However, there are gaps in relation to flyways and migratory bottlenecks.

The greatest threat to migratory seabirds from offshore wind development is collision with WTGs. The west coast, from the Gulf of Mannar southwards, is particularly important for migratory seabirds with up to 400,000 birds flying southwards during daytime. Non-marine migratory birds enter Sri Lanka through several entry points. Adam's Bridge provides one of the important entry points intro Sri Lanka for thousands of migratory birds arriving through the East Asian-Australasian flyway. Adam's Bridge Marine National Park is included in the exclusion zone.

AVISTEP, developed by Birdlife International, is an avian sensitivity mapping tool for energy planning [34]. It provides a useful assessment of bird sensitivity for different types of renewable energy projects, including offshore wind. Although the tool does not yet include an assessment of Sri Lanka, it does assess India and it scores the Gulf of Mannar as 'Very High' sensitivity.

7.3.6 Fish

Fish are identified as important features in two of the three Sri Lankan EBSAs, which are included in the restriction zone layer. The Southern Coastal and Offshore Waters between Galle and Yala National Park are designated for important fish species, and the Trincomalee Canyon and Associated Ecosystems for whale shark. No additional digitized spatial data has been identified in relation to fish.

7.3.7 Benthic Invertebrates

Sri Lanka has a total of 65 threatened marine invertebrates, comprising eight species of sea cucumber (Holothuroidea), 56 species of stony coral (Scleractinia), and one Octocoral (Helioporacea). All of these species are covered by the areas mapped as coral reefs, which are included in the exclusion zone.

7.3.8 Artisanal and Commercial Fishing

The fisheries sector plays a key role for Sri Lanka's economy and provides animal protein for the population. The marine fisheries of Sri Lanka consist of two main sectors, namely coastal fisheries and offshore/deep sea fisheries. The Sri Lankan fishing fleet is primarily composed of small (<12 m) vessels and approximately one third of this is non-motorized. In 2017 the production of commercial marine fish products was 439,370 metric tons. Of these, 17 percent was landed in the northern providence (Jaffna, Puttalam) and 21 percent was landed in the Southern providence (Tangalle, Matara).

Depending on the type of fishing activity, some fishing techniques may be more affected than others. Towed, mobile bottom gear techniques are more likely to be constrained by the presence of wind farm infrastructure, compared to mid-water fishing techniques. Fisheries are generally most intense in the coastal areas where they can be a constraint to offshore wind development.

Options for Sri Lanka include consultation with fishers and site selection to avoid interference with the most important artisanal and commercial fishing grounds and their biologically linked habitats (spawning, nursery areas), use of compensation schemes, and agreed multi-use areas (for example, allow transit, use of certain gear).

7.3.9 Tourism and Cultural Heritage

Ocean and coastal tourism are one of the fastest growing areas within contemporary tourism in Sri Lanka. While tourism development has been spatially focused on the beach for much of the past, the ocean and the marine environment as a whole has become one of the new frontiers and fastest growing areas of the world tourism industry. With this in mind, the Sri Lankan Tourism Development Authority (SLTDA) has been promoting coastal tourism in many coastal areas around Sri Lanka, with special emphasis on places such as Kalpitiya (northwest), Mannar (north), Trincomalee (northeast), and Arugam Bay (southeast).

This, in turn, is popularizing marine tourism, such as fishing, scuba diving, windsurfing, yachting, kite surfing, surfing, and whale watching at a rapid rate. Many international events are hosted in Sri Lanka, especially related to kite surfing, windsurfing, and surfing. The hotels and larger touristic areas are mainly located around Colombo, North of Colombo up towards Puttalam, and South of Colombo towards Galle and Matara.

It is generally recommended that siting of offshore development is located away from tourism hot spots. Floating offshore wind development may offer more opportunities to be located further from shore, away from tourism sites. However, the existing 17 wind power plants in the country have not hampered any coastal tourism related activities in Sri Lanka so far. In fact, wind farms may become tourist attractions on their own, and pinnacles in sustainable and renewable energy in the country. An example of this is the Bangui Bay wind farm in the Philippines [35].

Cultural heritage has not been specifically mapped for this roadmap exercise. There are no offshore sites included in the UNESCO world heritage list, however, obviously any offshore cultural heritage must be taken into consideration when planning an offshore wind farm.

7.3.10 Landscape and Seascape

In Sri Lanka there is no regulation on how far from the coast a wind farm should be. Since the visual experience of a windfarm is highly culturally dependent, a buffer zone for placing near shore wind is not defined in this roadmap. It should however be carefully considered during the planning process.

7.3.11 Military Exercise Areas

Data on military activities such as maneuvering exercises, firing practice, low-flying training, or testing grounds for ammunition are included in the Sri Lanka Air Force (SLAF) zones, see Figure 7.12. All SLAF zones should be considered for offshore wind development. However, some temporal activities such as laying of cables and transport of material is in many cases accepted by the military (following consultation) and thus accepted in the SLAF zones. All SLAF zones are included in the exclusion zone layer.

7.3.12 Ships and Navigation Routes

The shipping density according to Automatic Identification System (AIS) is highly concentrated outside Colombo and Hikkaduwa/Galle in the southwestern waters of Sri Lanka (Figure 7.12). In contrast, very few vessels are tracked in the northern waters of Sri Lanka, including Mannar Bay. The vessels traced by AIS are primarily tankers, while smaller boats are not registered with AIS technology.

Shipping is so widespread that it should always be considered when evaluating the construction of a new wind farm area or any other human activity offshore. Furthermore, shipping lanes must be considered as well in relation to the wind farm operation, due to the increased risk damage to wind farm infrastructure. Areas where the shipping density exceeds 1,500,000 boats/km^2 (over the period 2015-2020) are shown in Figure 7.12. There are no officially designated shipping routes in Sri Lankan waters and this figure shows that there is a significant amount of traffic spread over a large area.

Figure 7.12 also shows that there is a well-defined, informal shipping route to the south of Sri Lanka, starting slightly west of Matara and continuing in an easterly direction. Due to the extremely high density of shipping traffic, this has been designated as a restriction zone.

7.3.13 Subsea Cables

There are ten known submarine cables in Sri Lanka for communications (Figure 7.12). These are all located near Colombo and Hikkaduwa. Offshore wind activities such as laying of cables and transport of material are usually possible in the vicinity of existing subsea cables. Subsea cables are therefore not included in the restriction zone layer but should be factored into the planning of offshore wind farms.

7.3.14 Aviation

Offshore wind farms may interfere with aviation radar through shadowing or reflecting radar. In addition, offshore WTGs may block or degrade the signal for telecommunication and data transmission. In this context, areas around air traffic control centers (radars), airports, aerodromes, and air traffic zones can pose constraints for developers.

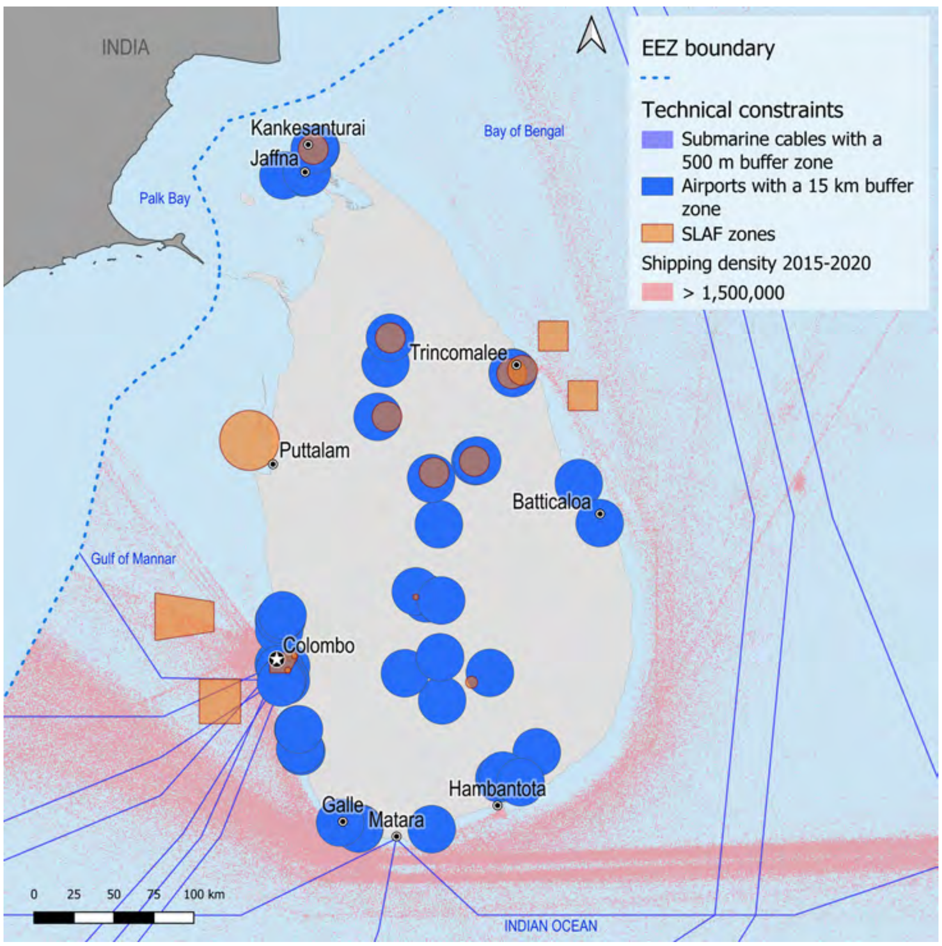
Several aviation related sites exist along the coast of Sri Lanka which could be a constraint for near shore wind development (Figure 7.12). The Sri Lanka Air Force (SLAF) regulates civil aviation in Sri Lanka and should be consulted in the early development stage of a specific offshore wind farm. Few SLAF zones exist in Sri Lanka and should be treated as exclusion zones. Furthermore, several known IKA airports are located along the coast. It is recommended that these sites are also treated as exclusion zones and a 15km buffer around these airports has been included as a precaution; however, consultations and radar studies will be required to explore this constraint further.

7.3.15 Oil and Gas Operations

Structures related to oil and gas infrastructure pose a hard constraint for wind farms and are surrounded by restriction zones. There are several existing oil and gas wells in Palk Bay and the northern Gulf of Mannar (Figure 7.12). These are included in the exclusion zone layer.

In 2019, Sri Lanka held an international bidding round to explore and produce oil and natural gas in the Mannar and Cauvery Basins. The Cauvery Basins blocks are not included in the Restriction or exclusion zone layers, but restrictions may come within the two block areas in the future.

FIGURE 7.12: SOCIAL AND TECHNICAL CONSTRAINTS FOR OFFSHORE DEVELOPMENT IN SRI LANKA.



7.3.15 Conclusions

The mapping of environmental, social, and technical constraints provides a preliminary high-level risk assessment of the values and characteristics that are likely to be critical when selecting one or more sites for offshore wind energy in Sri Lanka.

FIGURE 7.13: POTENTIAL AREAS FOR FLOATING AND FIXED FOUNDATION OFFSHORE WIND. NOTE, EXCLUSION ZONES ARE NOT SHOWN BUT HAVE BEEN REMOVED FROM CONSIDERATION.

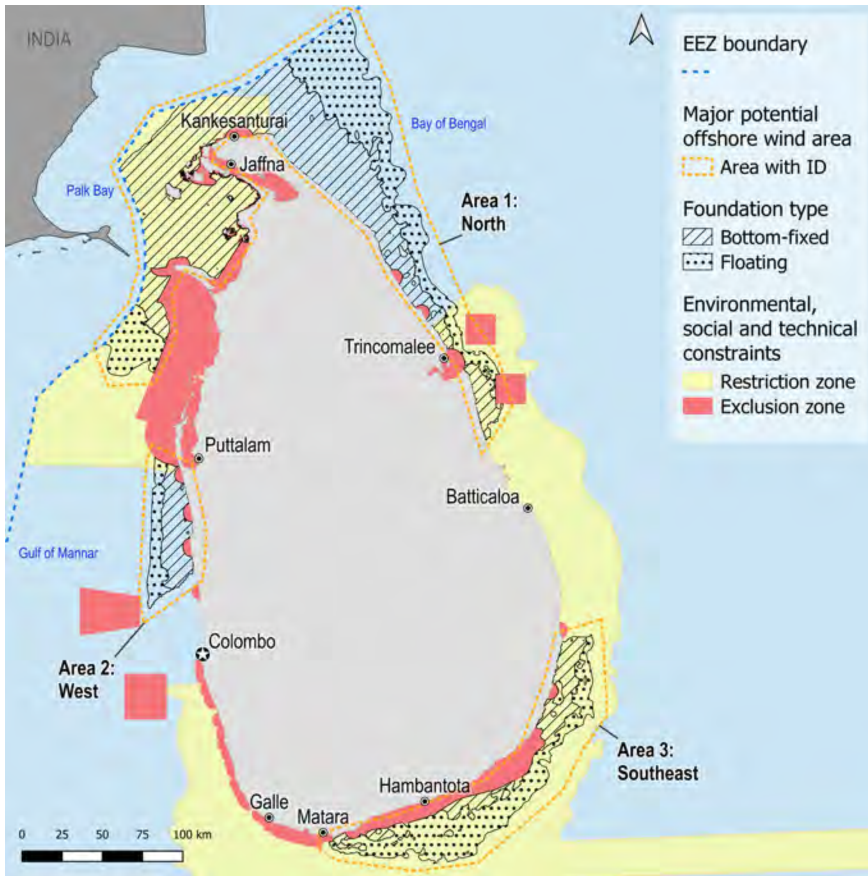


Figure 7.13 provides an overview of the exclusion zones and the restriction zones as recommended based on the constraint mapping. Large parts of the screened areas include exclusion zones where offshore wind farms cannot be recommended. The major constraints include conflict with legally protected areas, nesting areas for sea turtles, presence of threatened habitats (coral reefs, sea grass beds, and mangroves), foraging areas for threatened marine mammals (dugongs), major bird migration routes, and resting areas for birds.

In the northeastern area and in the waters between Puttalam and Colombo, there are relatively large areas considered lower-risk areas.

Some of the screened area within Mannar Bay and Palk Bay in the northern part of the country is mainly considered a high-risk area due to environmental constraints, which include the presence of major bird migrations routes, resting and breeding areas for birds, and threatened habitats (seagrass beds, corals, and mangroves) that are also habitats for threatened species of sea turtles and dugongs. For the same reason, large coastal areas from Jaffna to Puttalam are recognized as legally protected areas. In the southern and southeastern waters, the screened area for offshore wind development is likewise a high-risk area. Most of the nearshore, coastal areas are recommended to be excluded for development due to the presence of turtle nesting beaches and legally protected areas.

In the restriction zones, offshore wind farms may be feasible if the construction and operation of the windfarm is carefully managed and mitigating measures are integrated, e.g., by avoiding key sensitive periods for threatened species or by reducing physical damage of threatened habitats like coral reefs or seagrass beds by optimizing the positions of the WTGs. The restriction zones are categorized by various issues and mitigation measures will therefore be different from one site to another. This should be investigated further during the marine spatial planning, stakeholder engagement, site selection, and ESIA processes.

It should be noted that development within the restriction zones is likely to have a major impact on environmental, social, and technical aspects, and further investigations are needed to clarify the impacts.

Overall conclusions on the results are summarised in section 3.1.

8 REGULATORY FRAMEWORK

The regulatory framework surrounding offshore wind is critical to the success of the industry in any country. This chapter provides a basic analysis of the Sri Lankan regulation relevant for the development and operation of OWF projects in view of international regulatory experiences.

The regulatory framework shall provide the needed support in allowing for sound project development, access, and control over sites, and to ensure a reasonable exclusivity for developers to obtain a reasonable rate of return of the investment made. It must also sustain and orchestrate a sound process involved in at least three directions:

- First, the setting out of planning tools and process, such as development and active management of outcome related hereof to feasibility studies and assessments of risks, environmental and social impact, and site conditions, etc. Results from this must be taken diligently into account by sound risk management and mitigation planning.
- Second, to ensure a sound level of public consultation and participation in all planning and project stages.
- Third, to ensure an efficient coordinated involvement of all stakeholders, especially amongst all relevant public authorities needed for consent and permitting provision at national, regional, and local government levels.

As explored by this roadmap, for offshore wind projects, the issue of location and site management is less regulated compared to land-based facilities. For offshore projects, maritime spatial planning is key and rather often an innovation compared to the more traditional planning on land. Not only is it an innovation in terms of the legal framework, but also in terms of the actual implementation and need for well-coordinated and well-integrated planning solutions and outcomes. The offshore location may also bring about needed transnational coordination with neighbouring states and needed alignment with shipping and other activities in international waters.

Sri Lanka is a densely populated nation that presents challenges related to land use. The scarce land resources may provide legitimacy and support for offshore wind farm solutions. However, offshore wind projects will require new stakeholder engagements in order to obtain consent and legitimacy of long-term offshore wind exploration. Fishing and shipping communities, marine environment, local population, national security, oil and gas, and transnational interests may need to be included as new players. This may present additional challenges to the existing planning and permitting system and impede the timely implementation of new offshore wind projects.

Furthermore, the sound development and management of offshore locations may be challenged by military and national security interests as manifested by significant secrecy and security measures in place. Based on international experiences, this may require further efforts to ensure good planning and coordination amongst competent authorities (civil and military) in order to provide the needed access to site and supply lines, and to ensure proper planning, sharing of data and information, as well as public consultation.

It is not the intention of this roadmap to provide an independent legal analysis of these aspects but rather to assess the Sri Lankan legal and institutional framework based on consultations with relevant stakeholders combined with desk studies and analyze its suitability to deliver offshore wind.

8.1 OVERVIEW OF THE REGULATORY FRAMEWORK

Sri Lanka has many years of experience in tendering smaller scale renewable energy projects including onshore wind and hydro power projects, and now also in solar PV. The projects are based on independent power producers (IPP) and public private partnership (PPP) regimes and power purchase agreements (PPAs) based on feed-in-tariffs (FiT)[16]. All electricity generated by licensed producers is purchased by the Ceylon Electricity Board (CEB), and tariffs are approved by the Public Utilities Commission of Sri Lanka (PUCSL).

Currently, there are no offshore wind projects in Sri Lanka. Furthermore, there are no particular offshore wind regulations in place, although the importance of enhancing self-reliance and the continuous development of the renewable energy sector in Sri Lanka is emphasized as a part of the Ten Pillars of the National Energy Policy (2019) — pillar 7 with regard to renewable energy [36, 37]. Consequently, any possible OWF project launched today will need to base itself on the existing and non-offshore wind-specific regulatory framework. Stakeholders have expressed some belief in the ability of the current regulatory system to support the early development of OWF projects although the stakeholders also recognize the need for a future regulatory offshore wind reform to sustain the development of a future large-scale offshore wind market.

Such early offshore wind experiences based on the existing regulatory framework will allow for some learning, useful for a potential offshore wind regulatory reform in the future. However, as recommended in recent international studies related to the Sri Lankan energy sector, the regulatory reform process is needed already now in order to sustain the sound development of offshore wind projects [38, 22, 23, and 24]. The World Bank 2017 study observed that the current policy and regulatory framework is not consistent in nature to fully support the development of renewable energy projects in Sri Lanka, and a reform should also work towards disincentivizing development of fossil-based power generation plants [23]. This links to the overall and still valid conclusion already made in 2015 by the ADB concerning the future of the renewable energy market that Sri Lanka is still in need of implementing the revision of the Electricity Act in 2009[17]. ADB continues that "eliminating this primary root of the inefficiencies in Sri Lanka's power sector needs to be considered as the primary rationale for further reform" [24].

16 See for instance, [95] for the establishing of 60MW wind power plants on a PPP build, own and operate contract basis, and subject to International Competitive Bidding (ICB) — a template also available at [113].

17 The conclusions are still valid as based on stakeholder consultations. The Electricity Act has been amended in 2013 by [42], the Sri Lanka Electricity Act (Amendment) and in 2019, a special committee was created to amend the act.

8.2 MAIN INSTITUTIONS AND LEGISLATION

The main relevant authorities regulating, permitting, and preparing for renewable energy project tenders are included in Figure 8-1. These key institutions are:

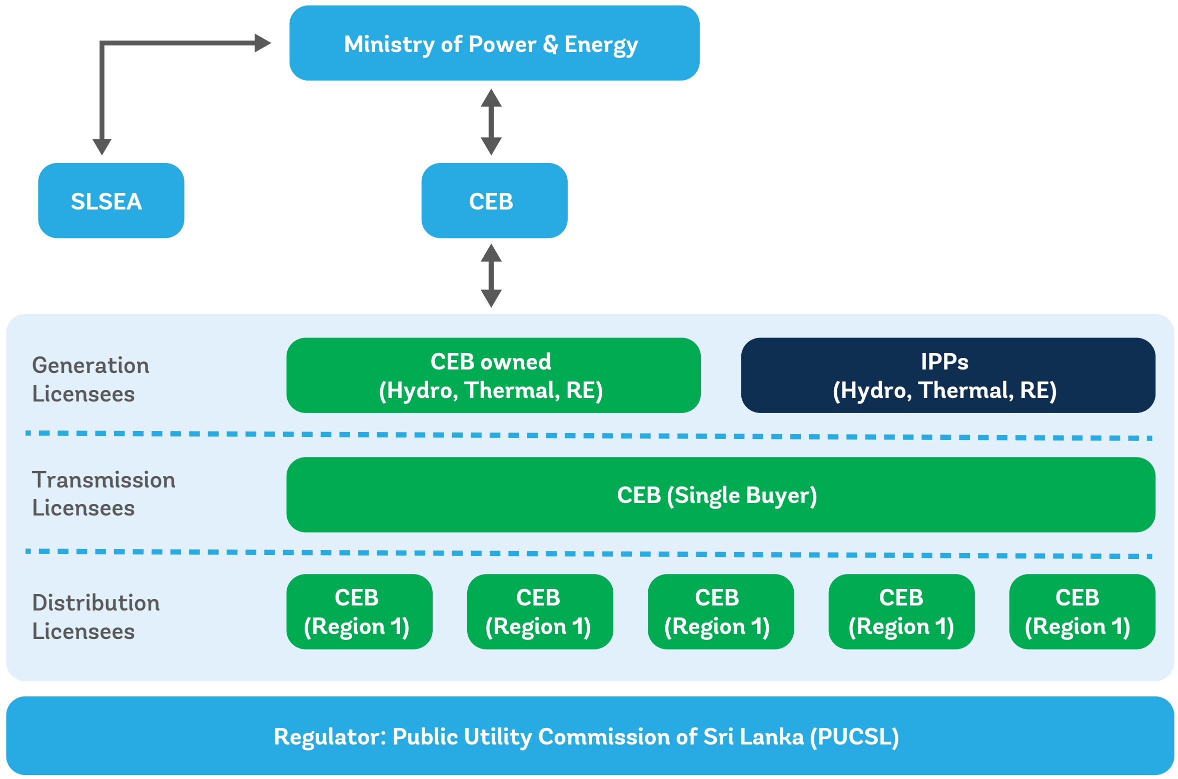
- Ministry of Power & Renewable Energy (MoPE). The Ministry undertakes the role of overall planning and policies and prepares energy policy, supervises the main state-owned power sector utility CEB, the state-owned distribution utility Lanka Electricity Company, Sri Lanka Sustainable Energy Authority, and several other state-owned entities in the energy sector [22].
- Sustainable Energy Authority (SEA) [39]. Regulator role of identifying and developing renewable energy projects, and in assisting in the development of renewable energy policies.
- Ceylon Electricity Board (CEB). Role of promoting and procuring renewable energy projects, and to purchase energy on set tariff structures, and to distribute power, as regulated by the Ceylon Electricity Board Act, 1969 [40].
- Public Utilities Commission of Sri Lanka (PUCSL)[18]. Role of regulatory oversight (i.e., tariff structures and methodology), market regulator and protection of consumer interest. PUCSL is the multisector regulator, which is presently empowered to perform the functions of technical, economic, commercial, and safety regulator of the electricity industry [22].
- Central Environmental Authority (CEA)[19]. Role of environmental impact assessment and ensuring environmental conditions.
- Board of Investment (BOI)[20]. Facilitating private, including foreign, investment.
- Lanka Electricity Supply Company (LECO) is the largest electricity distribution company in Sri Lanka. LECO is a state-owned electricity company operating under the license issued under the Electricity Act, under the regulations of the Public Utilities Commission and under the Public Enterprise Department guidelines. The company operates under the supervision of the Ministry of Power and Energy [41].

18 As regulated by the Public Utilities Commission of Sri Lanka Act, 2002. PUCSL was entrusted to regulate the generation, transmission, distribution, supply, and use of electricity by the Electricity Act No. 20 in 2009.

19 As regulated by Central Environmental Authority Act, 1980.

20 As regulated by the Board of Investments of Sri Lanka, 2012 (Amendment).

FIGURE 8.1: KEY ELECTRICITY SECTOR GENERATION, TRANSMISSION, AND DISTRIBUTION PLAYERS [23].



The primary legislation, in addition to the aforementioned institutional mandates, is the Electricity Act of 2009, amended in 2013 [42], regulating the electricity sector. The act regulates the generation, transmission, distribution, supply and use of electricity, and the procurement of new energy projects.

The environmental impact assessment (EIA), including the public consultation, is regulated by the National Environmental Act, 2000 and specific EIA Regulations[21]. The National Environmental Act also includes public consultation as part of the EIA process [43].

Planning tools are the following:

- The National Energy Policy & Strategies of Sri Lanka of 2019 sets the main objectives of Variable Renewable Energy (VRE) projects.
- The Sri Lanka Energy Sector Development Plan for a Knowledge-based Economy (2015-2025) sets out the roadmap for Sri Lanka to be an energy self-sufficient nation by 2030 [44].
- CEB Long Term Generation Expansion Plan 2018-2037, providing information on the existing generation system, generation planning methodology, system demand forecast, and investment and implementation plans for the proposed projects [45].

21 For VRE power plants, see [115].

8.3 PLANNING AND PERMITTING

8.3.1 Permitting and Procurement Process

The renewable energy permitting and tendering process may appear complex in nature considering the number of competent authorities involved[22]. In order to mitigate such complexity, the SEA provides a coordinated approach facilitating an integrated approach amongst the various permitting and competent authorities[23]. The aim is to provide a well-prepared tender process to enhance certainty related to the process itself, the obtaining of permits and PPA, and also related to improved risk identification allowing for better risk assessment and preparation for risk management and mitigation. The approach offered by the SEA is not a one-stop approach but is amongst the interviewed stakeholders found to be a welcoming improvement of the former system. Successful developers shall apply for approximately 20 relevant licensing and permits, such as an environmental permit by CEA, a generation licensing from the Public Utilities Commission of Sri Lanka in compliance with the Long Term Generation Expansion Plan, and a development permit based on these conditions, and obtain approval of the PPA based on feed-in-tariffs[24].

The current renewable energy projects are based on overall prior planning undertaken by the Ministry of Power & Renewable Energy (MoPE) and as assisted by the Sustainable Energy Authority (SEA)[25]. National planning is supplemented by local planning being revised every two years. Based on such planning, the SEA identifies and develops the renewable energy projects, whereafter either the CEB or the SEA — or the CEB and the SEA jointly — initiate the procurement process for tendering based on national competitive bidding (NCB)[26]. A mix of competitive procurement routes are employed. The exact route prescribed and the exact derisking profile/split between public sector and the private developer vary. However, the current tendering of the large-scale renewable energy projects — which in scope and complexity are likely to resemble the future OWF projects — reveals a high degree of private financing/request for investments and risk-taking. The process involves prequalification followed by competitive tendering resulting in an award and an exclusive lease right for the private developer, who in return are assigned with the responsibility to undertake the detailed site studies based on feasibility studies undertaken by public sector. As seen in the calls for proposal, the EISA may be part of the developer's responsibility depending on the particular tender design. However, for some calls the EISA may also be part of the studies undertaken by the public sector to derisk the project.

As described above, the developer is also required to obtain the permitting (assisted by the SEA as described above), which also includes the environmental permit from the CEA, which will address all environmental conditions.

22 The complex involvement of authorities, also beyond the main central authorities listed here, may be illustrated by the tender process for the Wind Power Generation in Mannar — a project based on EPC and PPA contracts. In this case, the SEA involves the CEA for environmental approval. The CEA then engages the Coast Conservation and Coastal Management Department (CCD) to lead the project for the environmental component. This calls for the involvement of the Department of Wildlife, local authority Pradeshiya Saba, Urban Development Authority, Fisheries, Irrigation, Divisional Secretary, and Civil Aviation Authority. Presentation held 19 February 2021 by Energy Management Forum: Wind Power Generation in Mannar by Eng. Kamal Illeperuma, Vice President Sri Lanka Energy Management Association (SLEMA), copy retained by COWI.

23 See for instance SEA call for expression of Interest (EoI) for the Supply, installation, commissioning, and operation of solar PV testing facility at Hambantota Solar Energy Power Plant, as announced at the SEA procurement site http://www.energy.gov.lk/index.php/en/procurement

24 In general, see [116], as amended in [42]. For the generation licensing, see [117].

25 For the planning of future RE project, including OWF, see the recent SEA Renewable Energy Resource Development Plan 2021-2026 at http://www.energy.gov.lk/images/renewable-energy/renewable-energy-resource-development-plan-en.pdf

26 The tenders are presented at the procurement sites; for SEA http://www.energy.gov.lk/index.php/en/procurement and for the CEB at https://ceb.lk/tender-notice/en

As regulated by the Electricity Procurement Rules, 2016, the tender documents also include the power purchase agreement based on feed-in tariffs. Before launching the tender, the PUC shall approve the tariff structure as proposed and set by the CEB. Having obtained the PUC approval, the SEA/CEB launches the tender, which will specify the tariff and payment structures, and the terms and conditions of the PPA.

After the conclusion of the tender process, the PUC needs to approve the draft PPA and its specifications. When approved and when having satisfied all other conditions and permits, the developer can request the generation license also from PUC and the development permit.

The CEB purchases all electricity generated by licensed producers in Sri Lanka. CEB sells the electricity to consumers or to LECO being the only other licensed distributor of electricity.

8.3.2 Stakeholder Perspectives

Although planning is in place, it has been informed during the interviews that planning in the past has not always been optimal in terms of land and site determination and preparations, and for the delineation amongst competing interests for land use.

The interviews pointed out that a need for better planning by zoning is needed for the development of renewable energy projects. Also, long-term planning is required as different interests at offshore locations may not be well-aligned in terms or utilization and access to particular areas, such as between oil and gas and offshore wind projects. Further coordination of such offshore activities should be addressed by enhanced and detailed integrated planning.

The interviewees also expressed some concern related to the lack of specific regulation and coordinated approach related to the readiness of offshore wind site preparation. This is related to the overall concern regarding the studies on site conditions as locations are not well defined and as information and data on site condition in general (e.g., related to wind and ocean characteristics) are not easily available.

The interviewed stakeholders did however refer to some positive recent experiences regarding project preparation and the preparation of tender design and tender process. Here, some optimism was specifically expressed regarding the increase in the environmental impact assessment and feasibility studies provided by the public sector. However, it is yet to be seen whether this trend will evolve with regard to the large OWF projects, as the current large scale project reveals a significant risk-taking by the private developer.

8.3.3 Discussion on Planning and Permitting

It is noted that any possible OWF project launched today will need to base itself on the existing and non-offshore wind-specific regulatory framework. Such an approach may work provided that the tender documents clearly will be able to accommodate the particularities of developing OWF projects. International experiences show that such an approach may prove difficult in providing the needed clarity and facilitation especially related to the undertaking of studies, planning, and permitting in a market driven by significant risk-taking and financing by the private developer. Instead, the successful development of offshore wind markets in Europa is based on dedicated and well-developed offshore wind legal regimes. The European markets operate with detailed tender documents and specification well-embedded within a OWF legal framework that provides certainty, reliability, and stability for the investors/developers.

Offshore wind planning and permitting also involves additional stakeholders that may emerge and new processes that have to be set in place. The location of offshore wind in the northwestern parts of Sri Lankan waters may invoke transnational environmental impact assessment and planning together with India, depending on the actual location and the international legal commitments engaged[27]. It also involves national security interests, and an active planning and possible permitting by the navy and military. It involves maritime special planning that takes other commercial activities into account, such as fisheries, coastal tourism industry, and shipping activities.

These shortcomings are to some degree identified by the 2019 WB/IFC study, as the study found a need for clearer roles and mandates in permitting and more guidance, coordination, and alignment amongst sector stakeholders, also to overcome complications of overlapping mandates. The study also calls for a genuine one-stop approach, as project developers observe a lack of adequate support from the government to complete the typical comprehensive approval processes within the stipulated timeliness[28]. Also, the ADR/UNDP 2017 study calls for an improved integrated national energy policy formulation across policy and legal framework[29].

Two final observations on the offshore wind permitting and the underlying studies and investigations relate to the need for robust baseline surveys and the ESIA to be completed to GIIP, and it relates to the alignment of regulatory framework and permitting to lender requirements to avoid delay in financing. These aspects need to be taken into account by the SEA, the CEB, the PUC, and also the SEA when setting the conditions and tariff structures for the particular offshore wind tender.

27 For instance, following possible bilateral agreements and/or signature to international law, e.g., the UNECE Espoo Convention on Environmental Impact Assessment (also open for UN members beyond the UNECE), although Sri Lanka is not party to the Convention.

28 WB/Infra SAP [2], p. 10, 54, and 58.

29 ADB/UNDP 2017 [23], p. 99.

8.4 PUBLIC CONSULTATION

Public consultation is an integrated part of the planning and preparation for renewable energy projects. The interviews have indicated, although not in detailed manners, that the consultation processes are not always well implemented[30].

Based on recent tenders in onshore renewable energy projects, it appears that significant focus in Sri Lanka already is being attributed to environmental and social assessments (ESIA) and related public consultations[31]. This is a sound approach considering the ability hereof to mitigate related adverse impacts due to the dense population, scarce land resources available and the significant social and land rights involved. The possible future offshore location may mitigate some of these concerns related to dense population and scarce land resources available. However, an offshore location will most likely involve additional and different stakeholders compared to the traditional land-based projects. This may cause some initial challenges for any environmental and social impact assessment, as well as consultation processes, in terms of process and management of outcome and expectations.

8.5 LEASE AND LAND RIGHTS

As mentioned previously, as part of the site and project preparations, past experiences have revealed challenges in relation to certainty in actual location and in the conditions of lease and land rights. Offshore lease/concession of seabed for private developers is already legally possible, as seen within the oil and gas sector under the Ministry of Petroleum and approval by the Cabinet[32]. It is assumed that similar lease for offshore wind projects will be based on firm legal basis provided by the Government of Sri Lanka.

Related to this, it has been noted that project implementation earlier was challenged by delays in land acquisition due to uncertainty in the land lease framework, and uncertainties related to recent significant increases in the leasing fees and lack of transparency into the allocation and valuation of state land[33]. To overcome such uncertainties, the WB/Infra SAP study recommends SEA to provide a clear framework for land acquisition in order to identify/select land parcels including an overview of potential locations, to provide a clear compensation scheme based on market price, and to overcome the internal delay in government processing[34].

30 It is noted that Sri Lanka is not party to the UNECE Convention on Access to Information, Public Participation in Decision-making, and Access to Justice in Environmental Matters (Aarhus Convention).

31 See for instance recent 2020 request for proposal (RFP) by the Sustainable Energy Authority (SEA) based on ToR from the Central Environmental Authority (CEA) on an ESIA for Proposed Wind and Solar Hybrid Energy Park Project in Pooneryn, procurement nr: SEA/PD/S/24/2020.

32 See for instance https://www.trade.gov/country-commercial-guides/sri-lanka-oil-and-gas

33 WB/Infra SAP 2019 [2], p. 54 and ADB/UNDP 2017 [23], p. 54.

34 WB/Infra SAP 2019 [2], p. 54.

8.6 MARKET ACCESS

8.6.1 Public Private Partnership

Sri Lanka has for many years recognized the significance of involving private partners to undertake infrastructure projects based on procurement processes and competitive bid [46]. Over the years, Sri Lanka has developed a tradition for public private partnership and involvement of IPPs. However, the private sector involvement is not generally considered to be a success story[35], and it is also found that the PPP regime employed seems more acceptable to domestic investors[36]. The ADB/UNDP 2017 study found that foreign and domestic institutional investors in Sri Lanka have been facing significant barriers to investment in the renewable energy sector, with numerous risks in the form of off-taker risk, currency risk, land acquisition, and regulatory risks[37].

Despite such challenges, it is generally recommended for Sri Lanka to look beyond publicly financed projects and increase the share of commercial financing and encourage greater private sector participation in order to meet its growing energy needs[38]. As such, and in order to attract private and foreign investment and to ensure bankable project structures as part of the overall enabling environment of the energy sector in Sri Lanka, the World Bank recommends a further strengthening of the PPP regime in Sri Lanka as part of a roadmap towards an improved power sector. The recommendations address in particular the need for clarity in the risk allocation involved, as well as improved transparency and clarity related to process, evaluation, government roles, and decision-making processes[39].

8.6.2 Procurement and Contracting

The general sentiment of the interviewees reveals that the current procurement and contract regime may provide a basic foundation to sustain offshore wind projects and attract foreign developers and investors. However, this may be in contrast to past experiences related to government procurement in Sri Lanka, where procurement from an international point of view could raise concern for lack of transparency and accountability in the tender process, and where tender specifications often were developed to suit a particular company[40].

It is also observed that the uncertainty involved in the procurement processes leads to a certain reliance on unsolicited proposals[41]. For such reasons, it is suggested to promote private participation based on a clear procurement process with a fair and transparent set of tender rules to maximize process efficiency, and also to maintain a multi-year pipeline of projects to continuously engage investors for development of the sector[42].

35 ADB 2015 [24], p. 28.

36 WB/Infra SAP 2019 [2], p. 16.

37 ADB/UNDP 2017 [23], p. 49s and 51s.

38 See WB/Infra SAP 2019 [2], p. 3.

39 See WB/Infra SAP 2019 [2], p. 52 and 60.

40 See WB/Infra SAP 2019 [2], p. 52s. The concern is raised as a general observation for government procurement however, under the heading of Sanitary and Phytosanitary Measures, which may refer to different kind of government procurement than applied/expected for OWF. However, the concern raised concerning lack of transparency and biased processes raises some overall concerns.

41 WB/Infra SAP 2019 [2], p. 53.

42 WB/Infra SAP 2019 [2], p. 52s.

In overall terms, the Sri Lankan legal regime seems to follow international recognized principles for competitive procurement schemes (restricted tenders), and for traditional contract paradigms based on PPA and feed-in-tariffs[43]. This provides some comfort to the international bidders. However, as the prevision studies have shown, issues are observed with regard to procurement and PPP. Moreover, the current tariff reform as introduced with the Electricity Act 2009 based on a separation of the costs related to generation, transmission, and distribution, and on recovery of all reasonable costs involved, has not yet been fully implemented, which has led to some public distrust in the tariff system. In addition, the current electricity tariffs are not always seen as cost-effective[44]. As such, the road map should explore the need for legal reform of the tariff methodology in the Electricity Act to fully take advantage of more adapt and flexible payment systems, which should include the possibility for CfDs in case of a future liberalized electricity market (a likely consequence of the transnational grid expansion in Asia — the cross-border electricity trade (CBET) initiative, see more below).

As the current renewable energy projects are relatively small scale, it could be questioned whether the current institutional capacity and experience level will be adequately able to meet international expectations on larger-scale offshore wind projects. Such large-scale projects call for advanced and resource-demanding competitive dialogue and negation procurement processes, as well as implementing contracts (e.g., EPC, DBFO, PPAs, etc.) for the effective management of larger scale OWF projects and the complexities they involve. It also calls for flexible pricing structures based on CfD (if the electricity market becomes further liberalized). Some learning could come from the experiences following the first OWF projects to come. A closer assessment of the procurement and contracting regimes should therefore be part of a later evaluation. As a consequence of this advanced approach, it is recommended to increase the knowledge and capacity of the Sri Lankan government in handling and undertaking procurement processes based on international PPP experiences[45].

Foreign Investment

According to the interviews, the regulatory framework is improving in attracting international developers and investors. Bidding and tender participation is also open for international bidders, and company registration and business operation carry no observed difficulties for foreign companies. The interviewees mention that the Board of Investment (BOI) may play an instrumental role in the particular tender in order to clear such difficulties in order to ensure an even playing field for all bidders[46]. However, certain financial requirements, such as aspects regarding currency conversion/depreciation may still be considered as major risk for foreign investors[47]. Such challenges have also resulted in a decline in foreign investments in the power sector from 2013 to 2017; however, this is primarily observed due to policy uncertainty[48]. This development may contrast information for 2016-2017 stating that general foreign business development in Sri Lanka is growing steadily [47].

43 See for instance, [95] for the establishing of 60MW wind power plants on PPP build, own, and operate contract basis, and subject to International Competitive Bidding (ICB) — a template also available at [118].

44 WB/Infra SAP 2019 [2], p. 4 and 12s and ADB/UNDP 2017 [23], p. x and 104ss.

45 See also WB/Infra SAP 2019 [2], p. 58s.

46 The BOI's overview of investment policies and related regulation provides guidance for domestic and foreign investors and illustrates at the same time the recent development in policies and laws enhancing private investment and partnership.

47 See also WB/Infra SAP 2019 [2], p. 5.

48 See also WB/Infra SAP 2019 [2], p. 5.

The market attractiveness depends rather obviously on the OWF project opportunities and the readiness/level of preparation of tender and project terms being offered by the Sri Lankan government. The interviewed stakeholders were not entirely convinced that there is a potential offshore wind market of large international scale in the near future. Perhaps in a longer ten years + perspective, as determination, maturing, and preparation of possible offshore wind sites will take place, more opportunities and market attractiveness are likely to occur.

8.6.3 Sri Lankan Grid

In comparison to the European grid system and its integrated access to an almost endless market, the OWFs in Sri Lanka may in the future provide power to be sold through an interconnector towards the Indian and Asian market. Sri Lanka is actively addressing the use of cross border electricity trade (CBET) initiatives as part of the National Energy Policy & Strategy of Sri Lanka[49]. Nevertheless, the domestic market may in itself provide an increasing business case as the demand for power, and the demand for renewable energy power in particular, is rising. The future of offshore wind in Sri Lanka is closely linked to the development of other possible renewable energy sources. As Sri Lanka most likely also in the future needs to optimise the use of the scarce land areas, offshore wind may stand well in this aspect taking into account that solar power is relatively land demanding. Finally, the tendencies of green investments going virtual (i.e., VPPAs) indicated that offshore wind investments are truly global. For such reasons, OWF projects may be an appealing business opportunity also in Sri Lanka.

8.7 INTERNATIONAL REGULATORY EXPERIENCES

To assess offshore wind market opportunities for Sri Lanka, it may be useful to draw on relevant offshore wind international experiences and lessons learned especially from northern Europe[50,51]. Any comparison between jurisdictions and markets shall be approached with caution as conditions typically vary. However, although it is not the aim of this study to provide a comparison with the Sri Lankan regulatory regime, the lessons from Europe provide inspiration as a well-regulated, integrated and transnational system, and as the European supply chain for offshore wind farms is mature and competitive, serving not only wind farms in Europe, but also some wind farms in more distant countries[52]. Companies from the UK, Denmark, Germany, and the Netherlands are the main participants in the supply chain, since the seas bordering these countries have seen the most growth in offshore wind[53].

49 See note 12 and points 3.1.11 and 4.1.1a of the National Energy Policy and Strategies of Sri Lanka: To realize energy security, feasibility of cross border electricity transfer with countries in the region will be studied and documented by end 2021, and viable cross-border electricity transmission and cooperation with countries in the region will be pursued on the basis of multilateral power pool operation.

50 Hohe See [106]
- Hornsea Project One [112]
Please note that this section is detailed on the Danish and UK regimes. For a further comprehensive overview of international regulatory practise and experiences, please see the recent World Bank Group's 2021 report "Key Factors for Successful Development of Offshore Wind in Emerging Markets". [17]

51 Regulatory lessons for this study are derived primarily from examples of OWF projects (recently in operation or planned), and based on the information provided:
- Denmark's Energy Islands [96]
- Kriegers Flak [97]
- Baltic 2 [98]
- Hesselø Offshore Wind Farm [99]
- Thor Offshore Wind Farm [100]
- Nearshore Wind Tender [102]
- Walney Extension [103]
- Horns Rev 3 [104]
- Beatrice Offshore Windfarm Ltd [105]
- Hohe See [106]
- Hornsea Project One [107]

52 The UK regulatory approach in planning and consenting, as well as in the supply chain related to all project phases is well documented in BVG Associates' 2019 "Guide to an Offshore Wind Farm. The guide lists the authorities, functions, supplier names, costs, key facts, and scope for supply chain items in each project phase from development all the way through decommissioning. Even though the guide is focused on the UK, the information given generally provide a good representation of the European market, since co-operation is common [49].

53 For the Danish regulatory approach, see the DEA's Energy Policy Toolkit [108], which provides a good overview of OWF planning and consents. As from 2015, the details of the legislation have changes, but the general legislative process is still the same.

In Europe, specific offshore wind national legislation addresses and directly encourages the development of OWF projects. Such legislation provides the needed certainty and stability to attract investments and developers. With this framework as a basis, public regulators prepare and manage the tenders in effective manners and include the public and other stakeholders in facilitating consultation and participation processes. The Danish and Dutch offshore wind legislation is for instance typically available in English and is based on same regulatory concepts[54].

The advanced European offshore wind market and regulatory framework is useful for three reasons: First, the European market and regulatory regime are products of a learning process. Second, being advanced provides useful benchmarking for global market standards and local regulation. Third, the European offshore wind market and regulatory framework to a large extent sets the bar for international investors'/developers' expectations and interests when assessing global market opportunities for bankable investments. An investment regime based on regulatory certainty and reliability in terms of market access and during implementation may prove to be a preferred business case. However, these aspects shall be seen in the specific context of each individual project opportunity as local projects may have unique attractiveness for international investors beside the aforementioned.

8.7.1 Planning

The key for any successful offshore wind is a well-planned process. It is a process being characterized by complexity in managing the many interfaces, risks, and interests involved, such as securing and sustaining a long-term partnership with a private contractor, ensuring optimal bankability and best competitive prices based on predictability and certainty in risk allocation, risk mitigation, and contract management.

Planning Based on Long-Term Goal

OWF projects are typically addressed in long-term national planning and further detailed by planning and specific legislation providing the legal mandates needed. The planning will also initiate the early consultation processes involving stakeholders and the public in general. These processes are useful in stimulating the needed legitimacy for the projects to come and to alert the market investors of possible new project opportunities.

Integrated National and Transnational Planning and Coordination

The locations of OWFs in the North Sea and the Baltic Sea are characterised by waters being shared by many states and being used as some of the busiest shipping routes in the world. As such, in addition to national planning requirements, a significant element of transnational planning and organization takes place. EU and national legislation, including international legislation (e.g., the Espoo Convention) and the regional sea conventions (i.e., OSPAR and HELCOM), require national and transnational environmental, social, and economic impact assessments, maritime spatial planning, and public consultation.

54 The Danish regulation provides an example: The conditions for offshore wind farms are defined in the Promotion of Renewable Energy Act. In chapter 3, it is stated that the right to exploit energy from water and wind within the territorial waters and the exclusive economic zone (up to 200 nautical miles) around Denmark belongs to the Danish State [109].

It is also a market driven cooperation and coordination amongst TSOs in the region encouraged by EU legislation and a market approach to optimize/utilize capacity based on economy of scale[55].

National and EU legislation require that offshore planning is based on an integrated approach. It follows from EU marine and maritime legislation, and from the Regional Sea Conventions that EU member states individually and in transnational coordination shall obtain planning taking all activities into account. The planning will in detail prepare for further development of OWF sites and ensure alignment with other planning and area use, such as for national security of military and navy purposes. It is not per se, a system that eliminates the secrecy and priorities associated with national security but rather a system that ensures coordination amongst interests.

8.7.2 Integrated Permitting

The national permitting for the development of offshore wind is primarily based on an integrated permitting system amongst authorities and a one-stop approach. This means that the applicant in most cases may only refer to one entry point, and that permitting will be coordinated between authorities as far possible. It should be noted, however, that all competent authorities will be involved and will issue permit conditions to be fulfilled by the developer. However, it is a system that significantly eliminates uncertainties related to the process, timing, and outcome of any system involving many permitting authorities, including authorities safeguarding national security issues.

As an example, in Denmark, three licenses are required to establish an offshore wind farm [48]. The three licenses are granted by the Danish Energy Agency (DEA), which serves as a "one-stop-shop" for the project developer. The three licenses are:

1. License to carry out preliminary investigations
2. License to establish the offshore WTGs (only given if preliminary investigations show that the project is compatible with the relevant interests at sea)
3. License to exploit wind power for a certain number of years, and an approval for electricity production (given if conditions in license to establish project are kept)

The three licenses are given successively for a specific project. Furthermore, it is necessary to perform an EIA if the project is expected to have an environmental impact. So far, it has been necessary to perform an EIA for all existing Danish offshore wind farms.

An integrated one-stop approach is not without several application phases in time and content. Depending on the tender terms, the successful winner may be required to follow-up and/or undertake specific permitting requirements as part of the project preparation and the undertaking of the EPC contract and possible following O&M contract. The level of involvement of the developer and the degree of risk attributed depends on the specific project. However, in order to eliminate uncertainty, European offshore wind tenders are typically well-prepared in order for the developer to take advantage of already issued permits and/or apply for permits based on well-developed feasibility studies and impact assessment.

55 The owners of the wind farms Kriegers Flak and Baltic 2, for example, have recently completed a joint 10-year project together with TSOs Tennet and 50Hertz to make the world's first combined grid connection between two wind farms [110].

Institutional lead agency is typically within the ministry of energy, being the energy agency — such as the Danish Energy Agency (DEA) — or an agency within management of natural resources and/or renewable energy infrastructure.

In the UK, the permitting system is also streamlined in five aspects [49]:

1. Before the consenting process can begin, the developer must secure a seabed lease by The Crown Estate (in 2017, a new body, Crown Estate Scotland, was formed to own and manage the seabed in Scottish Territorial Waters and adjacent areas of the United Kingdom Exclusive Economic Zone). The Crown Estate retains responsibility for the seabed in England, Northern Ireland, and Wales.
2. Offshore wind projects of more than 100MW installed capacity in England and Wales are defined as nationally significant infrastructure projects (NSIP) and are examined by the Planning Inspectorate.
3. The Secretary of State for the Department for Business, Energy, and Industrial Strategy (BEIS) grants or refuses consent based on a recommendation made by the Planning Inspectorate. In England, a Development Consent Order is granted under the Planning Act 2008 (as amended) which incorporates several consents, including a marine licence and onshore consents. In Scotland, Marine Scotland examines applications for the offshore works and Scottish Ministers grant or refuse consent under the Marine (Scotland) Act of 2010 (up to 12nm from shore) and the Marine and Coastal Access Act 2009 for projects 12-200nm from shore.
4. A streamlined process incorporates consent under Section 36 of the Electricity Act 1989 in parallel.
5. Onshore consent including where the transmission cable landfall is awarded by the relevant local planning authority (LPA), except where a project is handled under an NSIP in England and Wales, in which case the onshore consents are considered within the NSIP process. Developers typically build internal teams of about up to 50 staff during the development phase, which contract specialist packages of work to environmental and engineering consultancies and data acquisition and analysis companies.

8.7.3 Concession/Use of Site

The successful developer of an OWF site obtains a legal right for site access and concession of exclusive site exploration based on a long-term contract. The rights following the concession can be based on use, rent, or lease contract terms as an integrated part of the project agreement or the PPA.

The contract will stipulate the terms for site conditions, the construction of the OWF, the use of the site and the exclusive exploration. It will also include access areas, pipelines, and submarine cables. Depending on the terms of the tender and the contract, the developer may also be responsible for areas and pipelines at land until the designated connection point(s) to the grid system.

As explained, the Crown Estate/Crown Estate Scotland provides seabed leasing. In Denmark, this is provided by the Danish Energy Agency.

8.7.4 Market Access

Access to the European market is based on well-established procurement processes. Procurement takes place as a result of long-term planning and takes direct advantage of a liberalized and competitive energy market to meet the ambitious renewable energy policy goals and agendas at national and EU levels. As part of the procurement process, the competitive approach amongst bidders is deliberately being employed in terms of negotiation during procurement with the aim of empowering public private partnerships to utilize and tap into existing cutting-edge knowledge, expertise, and resources to develop, finance, and to implement offshore wind projects. This approach also typically involves a degree of well-balanced local content requirements to stimulate its domestic industry without jeopardizing the market attractiveness for foreign investors.

Derisking

The public private partnership allows for early involvement in the process, which again allows for securing an early-partner commitment to the project even before award of contract, to mitigate uncertainties and risks identified, and to obtain valuable insight from the bidders to further refine the details of the procurement material, such as technical and commercial details.

The market and the project owner itself need a certain level of project certainty and predictability to assess the attractiveness of the project. This calls for clear risk allocation and work division for both developer and the owner during construction and implementation, and the undertaking hereof must be reflected realistically in the implementation plan of the project. If such is not in place, there may not be any or limited participation/bids or that the prices offered will be high to cover the uncertainties. Additionally, there may be a risk of the developer defaulting during implementation if certainty is lacking. This means that projects to the extent possible are being derisked by well-prepared tenders and risk identification based on impact assessments and feasibility studies. Derisking also takes active part of the procurement negotiation itself, allowing the parties to identify risks, provide for agreed risk allocation within the tender requirements and to establish risk management and risk mitigation schemes.

In addition to certainty concerning site condition, access areas, and connection points/interfaces, certainty is also required by the legal and regulatory framework. The tender must be clear in designating contracting authority and outlining the process required, including permitting. Each bidder must undertake legal due diligence to identify possible regulatory shortcoming and risks, and these shall be addressed during the procurement stage.

Besides certainty in public law, legal certainty also requires certainty in clear contract terms between the parties. Contract format follows international recognized formats and regimes based on clear contract structures, such as EPCI (engineering, procurement, construction, and installation), design, build, finance, operate (DBFO), power purchase agreements (PPAs), and single or multi-contract regimes. A significant risk allocation is typically addressed by the price and payment structure involved. Feed-in-tariffs that were common in the past have been replaced by a structure based on 'on-going' market prices with derisking caps for both developer and contractor (e.g., based on CfDs).

Contracting and Procurement Strategy

This calls for a clear procurement strategy as part of the early stages of the planning for the project. As recent European offshore wind project experiences show, current procurement involves the following major categories which should be considered at an early stage:

- **Market sounding** is used prior to the launch of the official procurement to initiate an investigation into the current appetite/interest amongst the potential bidders at the international market. This insight is key to target the launch of the procurement and to level/optimize the details of the procurement material and the project conditions.
- **Public tendering** or auctions based on negotiation with prequalified highly eligible bidders. This allows for securing an early partner commitment to the project even before award of contract, to mitigate uncertainties and risks identified, and to obtain valuable insight from the bidders to further refine the details of the procurement material, such as technical and commercial details.
- **Use of internationally-recognized procurement processes and contract regimes** (e.g., EPCI/turnkey, single or multi-contract regimes, DBFO, O&M) tailored with specific conditions relevant for the particular project. Use of such recognized regimes enhance certainty and stimulate the interests for the project amongst international bidders.
- **Price structure based on on-going market prices with derisking caps** for both developer and contractor (e.g., based on CfDs).
- **Bidders to take more risk and responsibility for connection grid and points** (both in terms of construction and/or operation) towards TSO even at shore.
- **Site preparations** depending on the actual project. Where such preparation already is provided for by the government (e.g., initial environmental impact assessment (IEIA) to identify fatal flaws (if any) and pre-feasibility studies), it may constitute a derisking for the private developer (all depending on the tender terms) and procurement time may be shortened and to some extent also allow for certain derisking for the contractor.

The sound procurement and contracting of a large-scale offshore wind farm has a major influence on the success of the project. The costs involved and potential for profit or loss is much higher in comparison to smaller scale onshore wind farm projects. Therefore, the consequences of a poor contracting and procurement strategy can have a serious impact on the project financial performance.

European Grid

Market attractiveness is also sustained by a high level of European market access by a well-integrated, well-established, and stable grid system. Seamless integration amongst European states and markets, which promotes stability, and security are largely based on EU legislation and provides the investor or developer — and also the off-taker — with a high degree of certainty in terms of grid and supply certainty even in peak times and during fall-out events. The European energy market is characterized by high demand for renewable energy solutions, several national markets located in relative closeness to the OWF sites, and a public and commercial willingness to support the further development of offshore wind[56]. The concept of multi-linking is also seen as an efficient way to take best use of resources and can be expanded and enriched with energy storage capabilities or PtX technologies[57].

These facts stimulate the interests amongst investors, developers, and off-takers to embark on larger OWF projects, which may be costly but also likely to be profitable. These facts also stimulate virtual investments in the European market from the world outside. The tendencies of green investments towards virtual PPAs (VPPAs) based on an increased focus on price structures based on CfDs illustrates that the global energy market and related global competition in terms of attracting investors and also in terms of competition amongst the investors themselves truly are borderless.

Allow for Exploration and Exclusively Unless Reserved by Law or Planning

As part of the liberalized market for offshore wind, and to stimulate private development of offshore wind, the Danish legislation allows for active pre-investigations of possible offshore sites by private developers. Such pre-investigation will address and assess all relevant conditions related to the environmental issues, wind resource and ocean currents, and impact on shipping and other infrastructure. Based on an application from a private developer, exclusivity by the government may be granted for within a set timeframe to undertake such exploration and if positive conditions are found and approved, development and operation of the offshore wind may be granted under set terms.

This option is only valid for offshore wind eligible sites not reserved, used, or prohibited by planning, use, or law. This also means in practical terms that applications will not be granted for offshore wind sites reserved, or under consideration for being reserved, for public tendering by the government.

56 No viable technical solutions allow a large-scale wind farm to run without grid connection. Battery storage solutions are economical for use during a limited time on very small scale (less than 100MW) wind farm. PtX technologies are promising, but have not yet been applied to offshore wind and would and carry a very high risk in the first few applications

57 As Europe looks toward 180GW in the North Sea, such energy storage and distribution technology is seen as a more flexible, faster, and cost-efficient method of using offshore wind power, as well as to reduce transmission needs [111]. These hubs facilitate better linkage of all the power produced and provide opportunities for energy storage, in the form of electricity and hydrogen. This concept is especially interesting because the network connects not only wind farms, but countries: Germany, UK, Norway, Denmark, and the Netherlands.

9 FINANCIAL AND ECONOMIC ANALYSIS

This chapter assesses the financial viability of offshore wind and the important considerations to ensure that future projects are 'bankable' and able to attract lower-cost, large-scale debt financing. It also assesses the potential economic benefits that could arise through the development of the two offshore wind growth scenarios.

9.1 COST OF ENERGY

The LCOE wind is the most common point of comparison of potential offshore projects both nationally and internationally. The LCOE measures the total cost of producing energy from a specific site per unit of energy produced over the lifetime of the project. To do this, the LCOE discounts all future costs and energy generation to today's value using the Weighted Average Cost of Capital (WACC).

$$LCoE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Levelized Cost of Energy:

I_t : Investment cost in year t
M_t : O&M costs in year t
E_t : Energy generation in year t
r : Discount rate
n : Project life

The main inputs for the LCOE estimation are capital expenditure (CAPEX), operational expenditure (OPEX) (i.e., O&M costs), annual energy production (AEP), project duration, and the cost of capital. The cost of capital is important in Sri Lanka because the local debt interest rates are very high. It is expected that offshore wind will have to be financed to a large extent by international banks and concessional finance. Hence, the impact of the cost of capital is examined in a sensitivity analysis. Likewise, the lack of on-site wind measurements results in a considerable uncertainty on the available wind resource, which will also be addressed by way of sensitivity analysis. The assumptions used are summarized in Table 9.1.

TABLE 9.1: INPUT ASSUMPTIONS FOR THE LCOE ESTIMATION.

Input	2030 Low Growth Scenario (0.5GW)	2030 High Growth Scenario (1GW)
CAPEX (US$ per MW)[58]	2.5 million	2.5 million
OPEX (US$ per MW)[59]	100,000	100,000
Net AEP (GWh/year)[60]	Central: 1,907 High: 2,188 Low: 1,627	Central: 3,821 High: 4,383 Low: 3,259
Technical life (years)	25	25
Weighted Average Cost of Capital (WACC) (%)	4%-12%	4%-12%

Note that the CAPEX and OPEX assumptions are the same for both scenarios. For both scenarios, it has been assumed that the total 2030 capacity (whether 500MW or 1,000MW) would be delivered by projects with a capacity of no greater than 500MW (this could potentially include multiple smaller projects), therefore, no economies of scale have been included. In established markets, large cost reductions have resulted from scaling up projects to 1,000MW or greater, however, the small scale of the Sri Lankan grid means that it will not be possible to connect a project of this magnitude at a single point. The strength and stability of the grid will therefore limit a project's capacity.

The results of the LCOE estimations are presented in Figure 9.1. The impact of the cost of capital is seen as the LCOE increases as WACC increases. Uncertainty on the wind resource is shown as a grey band around the central estimate. The wind resource uncertainty is explored by using P50 and P90 estimates as high and low estimates.

In both the low growth and high growth scenarios, the LCOE could be as low as US$65 per MWh and as high as US$155 per MWh depending on the cost of capital and the wind resource. Assuming sufficient risk mitigation measures and support from blended concessional finance that brings the WACC down to six percent, the LCOE for a project delivered by 2030 is expected to be approximately US$90 per MWh and possibly as low as US$75 per MWh depending on the wind resource. Electricity costs could be further reduced if a grant element is introduced as a form of viability gap finance.

This analysis assumes capital is provided in hard currency (US$ or EUR). The electricity tariff however will likely be paid in Sri Lankan rupees. To minimize WACC, it will be important to mitigate the currency exchange risk. One option could be the sale of power to other countries (via a future interconnector with India) and, for example, Bangladesh offers US$ denominated PPAs.

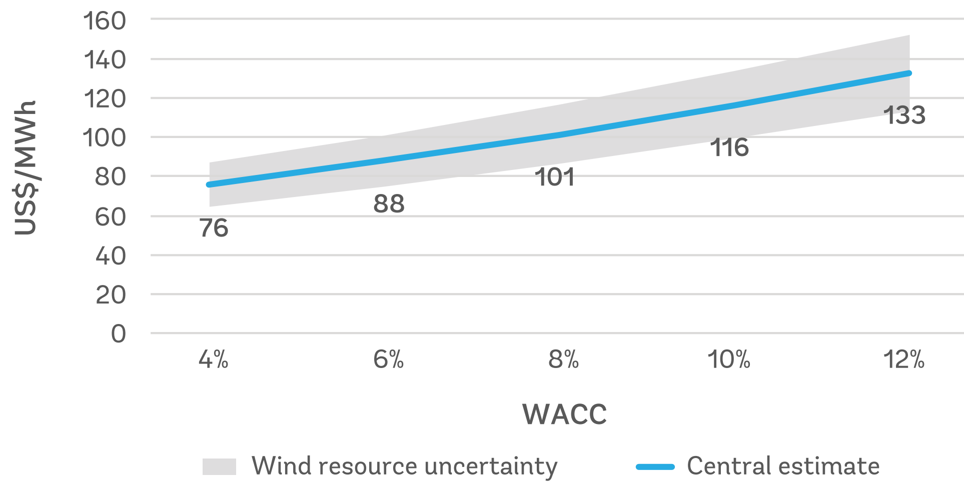
This wide range of different options to reduce WACC and the cost of electricity will need to be considered in future studies, taking into account a more accurate assessment of costs and risks.

58 CAPEX estimate is based on IEA Energy Outlook 2021 [114] Table B.4a. Numbers are adjusted to reflect start of construction in the mid-2020s.

59 OPEX estimate is based on IEA Energy Outlook 2021 [114] Table B.4a. Numbers are adjusted to reflect a COD in the late 2020s.

60 A generic ten percent loss from electrical losses and downtime is applied to the AEP after wake losses. At P50 this corresponds to approximately 50 percent net capacity factor.

FIGURE 9.1: LCOE ESTIMATES DEPENDING ON WIND RESOURCE AND WACC.



In the high growth scenario, LCOE is expected to be the same due to the fact that the expected capacity factor for the 1GW plant is assumed to be the same as the capacity factor for 0.5GW (50 percent CF). At the same time, significant cost reductions are limited, as 1GW of capacity is not sufficient to develop a local supply chain or gain economies of scale over 0.5GW of capacity.

The range of LCOE estimates provided in Figure 9.1 clearly demonstrate the need for addressing two significant uncertainties in the development of Sri Lankan offshore wind — the cost of capital and the wind resource.

Despite the large LCOE uncertainties, offshore wind could be competitive with new thermal generation. For example, the cost of new LNG fired generation is expected to be between US$90 and 120 per MWh (equivalent to 9 to 12 US Cent/kWh, see section 2.2).

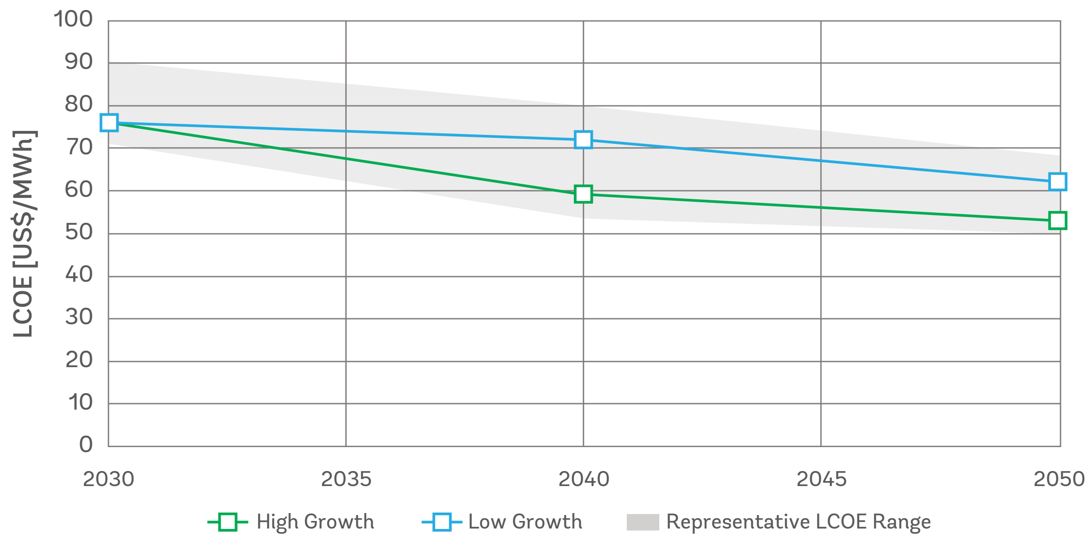
9.1.1 Cost Trajectories

Cost trajectories towards 2050 will be subject to a high degree of uncertainty. There are many factors which will influence the future cost of offshore wind in Sri Lanka. Global trends in technological development and efficiency gains in installation and operation of offshore wind farms play a role. So does the rate of build-out of offshore wind capacity in Sri Lanka, development of the domestic supply chain, and market conditions for the independent power producers amongst others. Finally, the development of an offshore industry in India has the potential to bring large benefits to Sri Lanka in terms of lower costs and possibly also jobs and economic growth in supporting industries.

The cost trajectories provided here are based on learning curves. Learning curves are a simple way of relating cost reductions to increases in installed capacity. The International Energy Agency [50] has estimated a learning rate for offshore wind of 15 percent. Every time installed capacity doubles, the cost is reduced by 15 percent. Globally, the 15 percent learning rate corresponds to a 40 percent cost reduction by 2030. However, this is a global average dominated by existing installation. For an emerging market, the 40 percent cost reduction by 2030 is not directly applicable. In an emerging market, the 15 percent learning rate should be applied to the expected pipeline of offshore wind capacity in the country or region. Furthermore, the 15 percent learning rate should not be applied to the very first offshore wind capacity — otherwise doubling capacity will happen at an unlikely pace.

The estimated cost trajectories for Sri Lanka in the Low and High Growth scenarios expressed in terms of the LCOE are provided in Figure 9.2. In both scenarios, it is assumed that the learning rate of 15 percent does not take effect until after installation of the first 800MW offshore wind capacity.

FIGURE 9.2: LCOE TRAJECTORIES IN THE LOW GROWTH AND HIGH GROWTH SCENARIOS, INCLUDING A RANGE OF REPRESENTATIVE LCOE DUE TO UNCERTAINTIES.



From a level of approximately US$75 per MWh in 2030, the LCOE of offshore wind in Sri Lanka could drop to US$60-70 US$/MWh by 2040 and US$50-60 per MWh by 2050. These cost trajectories are based on the installed capacities provided in section 6.2. Furthermore, the LCOE estimates are based on a six percent WACC. As with the main estimates for 2030, these cost trajectories are heavily dependent on the cost of capital and the wind resource. The installed capacities in Sri Lanka are still relatively small in 2050, resulting in moderate cost reductions.

In relative terms, the cost trajectories result in a 20 to 30 percent cost reduction by 2050 relative to 2030.

9.2 BANKABILITY AND INTERNATIONAL FINANCING

Offshore wind projects represent massive capital investments with very long payback times. The CAPEX of 500MW offshore wind project, for example, is typically US$1,250 million. Under a typical limited-recourse project financing structure, around US$1,000 million of the CAPEX would be bank debt. This puts emphasis on the financing of the projects and the ability of the project to not only attract investors but also to secure lending on reasonable terms. The typical debt to equity split for offshore wind projects is in the range of 65/35 to 80/20 depending on the track record of the developer, the experience of the banks, and the overall risk profile of the project[61].

For many emerging offshore markets, the first offshore project will seek a mix of local and international lending. The local banks provide local knowledge, bridge language barriers, and manage cash flows in the local currency. The international banks provide knowledge of offshore wind projects, provide risk mitigation, and lending at favorable rates. That said, the cost of capital from local banks in Sri Lankan rupees could be as high as 15 percent and there is limited liquidity available locally. International lenders may therefore be required to cover the majority, if not the entirety, of the debt.

61 It is assumed that offshore wind projects in Sri Lanka will use project financing.

The bankability of offshore wind projects — i.e., the willingness of banks to provide the necessary lending — depends on many factors. Banks must assess the track record of the developer, the political and regulatory stability over the lifetime of the project, risk allocation and risk management, and the business case of the project. Some of the main risks affecting the bankability of projects are likely to include:

- **Environmental and social risks.** The majority of potential sites in Sri Lanka have notable E&S sensitivities. An ESIA which meets international lenders' requirements will help to identify and mitigate this risk.
- **Grid connection agreement.** Connection of generation at this scale will be technically challenging for Sri Lanka's grid. Sufficient provisions will be required to address the risk of connection availability and establish appropriate compensatory mechanisms.
- **Power purchase agreement (PPA).** A long-term PPA will be required to provide revenue certainty. The PPA's terms, especially compensation for curtailment, will be critical to the bankability of the project. The PPA's terms will need to recognize the differences between offshore wind and other generators.
- **Offtaker creditworthiness.** Lenders will need confidence in the offtaker's ability to cover its payment liabilities over the lifetime of the PPA. Government backstopping to guarantee the PPA is likely to be required.
- **Political risk.** Lenders will investigate the likelihood and implications of policy, regulatory, and contractual amendments that could be made by future governments and whether that could impact the project's expected revenues. Insurance many be required to cover this risk.
- **Exchange rate.** The future exchange rate of the Sri Lankan rupee is unknown, and its volatility will impact revenues to service foreign debt unless sufficiently mitigated through some form of hedging or other instrument. Given the recent currency devaluation, this will be a major consideration.

See section 3.6 and 4.5 of the Key Factors report [17] for further discussion on the bankability of offtake agreements and the financing of offshore wind in emerging markets.

9.2.1 Developer Track Record

Offshore wind is a massive undertaking. The complexity and scale of offshore wind projects is not comparable to onshore wind. Although Sri Lanka has seen a surge in renewable energy projects, the scale for wind power projects remains small in the 5-10MW range except for the recently commissioned 100MW Mannar wind farm. For large scale offshore projects of 500MW or more, it will be necessary to bring in experienced international developers for the first pathfinder projects. This will reduce risk, leading to lower costs and a higher likelihood that the first projects will be successfully delivered. Over time, a collaboration between international and national developers will hopefully transfer the necessary knowledge and experience to the local developers.

The track record of the developer may also have a direct impact on the cost of capital. The cost of capital — most notably the interest on loans — will depend on the lenders' assessment of the risk of the project. The developer's ability to manage the risks and carry the project to success is a major evaluation criterion for the lenders.

There is a limited number of capable, experienced international offshore wind developers and, as many new offshore wind markets begin to emerge around the world, Sri Lanka will be in competition with many other offshore markets for the attention of the international developers. Sri Lanka should establish itself as an attractive opportunity by clearly stating its long-term future vision for offshore wind and providing a stable, clear, and robust regulatory framework to deliver that vision.

9.2.2 Political and Regulatory Stability

The tenor on loans for offshore wind are typically more than ten years and often upwards of 15 years or more. This kind of long-term exposure demands a careful examination of the political and regulatory stability in Sri Lanka.

According to feedback from stakeholders, the expressed commitment and support of the Sri Lankan government to offshore wind is vital for success. This support comes in the form of transparent regulation, clear permitting procedures, and funding.

Public funding has a direct impact on the business case of offshore wind projects. It must be expected that the first offshore wind projects in Sri Lanka will require a substantial public subsidy and support to provide the necessary returns to attract financing. A lack of a clear political commitment to a reasonable funding scheme can halt the development of offshore wind at a very early stage, so it is important for a commitment to be announced early to increase the industry's confidence.

The potential risk of major reversals of policy must also be considered for projects spanning decades. It is reasonable for investors and lenders to do an in-depth assessment of the stability and commitment of the Sri Lankan government to offshore wind — not only in terms of funding, but also in terms of permitting and licenses.

9.2.3 Lending Capacity of Local Banks

Local banks have experience with project finance through numerous smaller renewable energy projects in Sri Lanka These banks have built familiarity with the specific risks and uncertainties involved in renewable energy development in Sri Lanka. However, the larger scale and complexity and long timeframe of offshore wind will be a challenge for the local banks.

As mentioned previously, the tenor on loans for offshore wind are typically more than ten years and often upwards of 15 years or more. It must be noted however, that local banks in Sri Lanka will likely be unable to provide loan tenors in excess of eight years, and to provide loans on the scale associated with offshore wind development. In addition, the interest on debt in local banks is high — close to 18 percent in some cases. This makes it difficult to integrate local banks in the lending structure for offshore wind projects.

Integrating local banks in the financing of offshore wind is important not only to the specific offshore wind project, but also as a way to develop the local financial sector to take an increasing stake in future offshore development. Thus, solutions must be developed to support the local banks and enhance their capabilities in terms of providing longer tenors and lower interest rates. Stakeholder feedback from local banks suggest that they are very interested in collaboration with international development banks that can provide guarantees and funding support to help the local banks.

9.2.4 International Lenders' E&S Requirements

Before committing to an investment, both concessionary finance providers and commercial project finance lenders will carry out due diligence on a project's compliance with environmental and social performance standards. The International Finance Corporation's (IFC) performance standards (PS) require projects to meet minimum requirements in respect of biodiversity protection (PS6) and cultural heritage (PS8). IFC PS1 requires the assessment of these and other issues through Environmental and Social Impact Assessment (ESIA) to Good International Industry Practice (GIIP) and community engagement. Similar provisions apply to most private sector providers of finance, either through proprietary standards or through the application of the Equator principles.

Failure to meet these standards may leave projects with fewer financing options or preclude investment altogether. Building these performance standards into the regulatory framework for offshore wind is therefore likely to improve the bankability of projects, as well as delivering increased environmental and social benefits while avoiding significant harm.

9.2.5 Business Case

The main driver for bankability on a specific project will always be the business case. A well-documented feasibility study that demonstrates sufficient cash flow to service debt and provide dividends to equity is a must. Among the many unknowns in a 25- to 30-year business case, a few stand out: the wind resource and the cost of capital.

The wind resource in Sri Lanka is good, providing capacity factors above 45 percent in several areas. Thus, the wind resource is clearly sufficient for offshore wind. The main cost drivers for offshore wind in Sri Lanka are rather the CAPEX and the cost of capital.

The cost of capital in Sri Lanka is quite high. Stakeholder feedback suggests that interest rates on loans in Sri Lankan rupees could run as high as 15 percent. Add to that the fact that Sri Lankan banks will likely be unable to provide loans on the scale and with the tenor needed for offshore wind. The alternative is financing in US$ or EUR through international financial institutions. This could provide a significantly lower cost of capital, but at the same time increase the project's exposure to exchange rate risk.

Managing the exchange rate risk will be central to any offshore wind project in Sri Lanka in the foreseeable future. The exchange rate risk is often split between offtaker and developer through a combination of several strategies. One strategy is indexing of the PPA tariff, which will alleviate some of the developer's/IPP's exposure to the local currency. Another strategy is for the international financial institutions to take some of the risk, by providing loans in the local currency at aggressive rates.

For offshore wind, the majority of foreign currency denominated cost is anticipated to be in upfront capital cost, associated with the import of turbines and balance of plant, and ongoing debt repayments. From the operational perspective, ongoing operating costs are unlikely to require material foreign currency denominated input. There is opportunity for local developers to minimize foreign exchange risk through entering into hedging arrangements, such as foreign exchange swaps for the operating costs.

However, as the financing cost and debt repayment will be in foreign currencies, there would still be a need for foreign currency availability to the project operators through the project lifetime.

The CAPEX of offshore wind projects is closely linked to the ability of the local industry to supply locally manufactured parts and provide skilled labor. The first offshore projects in any emerging market are typically dominated by import of materials and expertise. Over time, the collaboration between international developers and local entrepreneurs will transfer knowledge and help establish local manufacturing. A political commitment to a pipeline of offshore wind projects will also provide the planning horizon needed for local industry to invest in the offshore supply chain. The LCOE estimates presented in section 9.1 are based on limited involvement from local industry.

9.3 EMPLOYMENT AND ECONOMIC BENEFIT

The calculation of the employment effects is based on Leontief multipliers[62], total production output, and annual employment data by economic activity. The employment and investment effects can be split into two: direct and indirect impact. The direct effect is the increased activity, created by the investment itself. This will include tasks such as development, supervision, installation, and construction work. The indirect employment effect is the increased demand for labor, which occurs as a result of procuring goods and services, and the effect this has with the supplier. The employment effects are measured in full-time equivalent (FTE) years, which corresponds to one individual working full time for a year.

The input-output tables [51] splits Sri Lanka's economy into 34 sectors, and the Leontief multipliers are calculated on basis of these input-output tables. To use the Leontief multipliers to assess the impact of an investment, the investment must be linked to a specific sector [52]. Offshore wind projects are large and complex projects typically spanning several key sectors such as construction, manufacturing, and marine transport. This effect is achieved by creating a weighted average of the relevant sectors based on the expected contribution from Sri Lankan sectors and the supply chain study in section 13. The estimated weights are provided in Table 9.2.

TABLE 9.2: WEIGHTED SECTORS FOR THE INVESTMENTS.

Activity	Sector Weights
Offshore wind construction	Construction: 85% Transportation and storage: 10% Manufacturing: 5%
Offshore wind O&M	Construction: 60% Transportation and storage: 40% Manufacturing: 0%

The cost estimates for a representative 500MW of offshore wind and its associated O&M are the same as those used for the LCOE estimation. These estimates are also assumed to be similar for 1GW and 2GW of offshore wind. Over time and in line with the learning rates applied in section 9.1.1, the cost of offshore wind is expected to fall. The total construction and operation and maintenance cost estimates are provided in Table 9.3.

62 Method developed by Wassily Leontief, to estimate the impact of an increase in production in one sector on all other sectors in the economy. The method is based on detailed input output tables from national accounts statistics and estimates a constant factor by which increased activity in one sector impacts the whole economy. These factors or "multipliers" typically have values in the range 1.5-2 implying that e.g., a 1 mUSD investment in a specific sector will increase the total activity in the economy by 1.5 to 2mUSD.

TABLE 9.3: TOTAL LIFETIME, DIRECT INVESTMENT NEEDED DEPENDING ON TOTAL INSTALLED CAPACITY IN SRI LANKA.

Activity	Scenario and Year	Total Lifetime Expenditure (US$ million)
Construction, O&M of 500MW of offshore wind (25-year lifetime)	LG 2030	2,500
Construction, O&M of 1GW of offshore wind (25-year lifetime)	HG 2030	5,000
Construction, O&M of 1GW of offshore wind (25-year lifetime)	LG 2040	4,745
Construction, O&M of 2GW of offshore wind (25-year lifetime)	LG 2050	9,075
Construction, O&M of 2.5GW of offshore wind (25-year lifetime)	HG 2040	9,569
Construction, O&M of 4GW of offshore wind (25-year lifetime)	HG 2050	15,104

A key source of uncertainty in the estimation of the economic impacts of offshore wind development is the share of the activity which is expected to be delivered by local enterprises. Although Sri Lanka has experience with onshore wind and renewable energy development in general, the scale and complexity of offshore wind is new territory. Stakeholder feedback suggests that considerable international expertise, manufacturing, and labor would be needed for the first offshore projects.

The local content is expected to increase, as Sri Lankan industry gains experience with offshore wind development. On the O&M side, local content is expected to be much higher, as the activities are distributed over many years allowing extensive use of on-the-job training and transfer of expertise.

The assumptions on local content are summarised in Table 9.4. The percentages shown in the table indicate the expected average local content of the entire investment needed to reach the total installed capacity in the leftmost column. The local content is primarily expected to be in the form of labor. The percentages are purely based on qualitative feedback and should be considered very uncertain and only indicative.

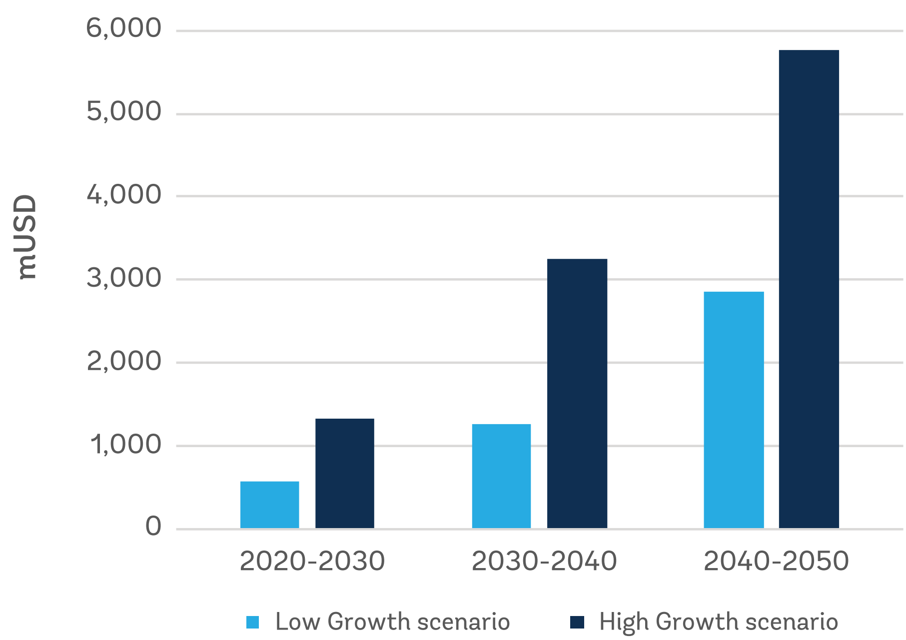
TABLE 9.4: LOCAL CONTENT SHARE OF THE CONSTRUCTION AND O&M OF AN OWF.

Activity	% of CAPEX Spent Locally	% of OPEX Spent Locally
250MW of offshore wind	5%	20%
500MW of offshore wind	10%	20%
1GW of offshore wind	10%	25%
2GW of offshore wind	15%	25%
2.5GW of offshore wind	15%	30%
4GW of offshore wind	20%	30%

As the offshore wind pipeline and the installed capacity in Sri Lanka grows, the share of local content can be expected to grow. As more local knowledge and expertise is accumulated, there will be less need for international support for the development and construction of projects.

The cumulative impact on Gross Value Added (GVA) from investments in offshore wind is illustrated in Figure 9.3. The chart shows the impact on GVA from offshore wind projects over their lifetime sorted by the expected time of commissioning. The two growth scenarios in this roadmap consider 0.5 to 1GW offshore wind capacity could be commissioned by 2030. During construction and over 25 years of operation these projects could generate between US$570-1,330 million US$ in GVA in Sri Lanka.

FIGURE 9.3: CUMULATIVE LIFETIME GVA FROM OFFSHORE WIND INVESTMENTS.



Note: The bars show the total lifetime impact of projects commissioned in a given decade, i.e., construction plus 25 years of operation.

The total impact on Sri Lankan GVA from construction of 500MW of offshore wind and O&M the site is expected to be approximately US$570 million over 25 years, of which US$380 million is the direct investment (i.e., CAPEX and OPEX) and US$190 million is the expected indirect investment[63] (activity in other sectors as a result of the activity set in motion by the direct investment). The indirect activity is determined by the country specific Leontief multipliers. Table 9.5 shows the impact on the GVA in 2030 in the low growth and high growth scenarios.

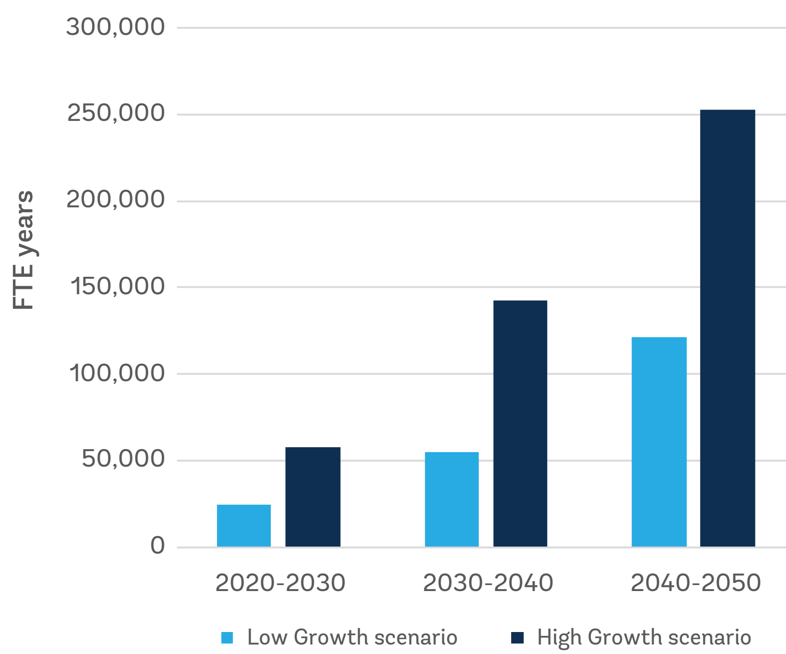
The application of input-output multipliers implies a linear relation between installed capacity and GVA impact. This linear connection is a reasonable approximation in the short term. In the long term, cost reductions, learning curves, and productivity gains will likely result in a declining marginal GVA impact per MW installed capacity. Simply put, each MW of additional capacity becomes cheaper than the previous MW, reducing the impact on GVA and employment.

TABLE 9.5: IMPACT ON DOMESTIC GVA IN 2030.

	Direct Investment (US$ million)	Indirect Investment (US$ million)	Total Impact on GVA (US$ million)
Low Growth scenario (500MW)	380	190	570
High Growth scenario (1GW)	880	450	1,330

The total local employment effect from investing in and operating and maintaining a 500MW of offshore wind is estimated to be almost 25,000 FTE over the lifetime of the project. This includes both direct and indirect effects (see Figure 9.4). This chart is structured in the same way as for GVA, i.e., it shows the total lifetime impact of projects commissioned in a given decade.

FIGURE 9.4: ACCUMULATED LOCAL EMPLOYMENT EFFECTS FROM OFFSHORE WIND INVESTMENT.



63 The indirect effect is the increased demand for goods and labor, which occurs as a result of procuring goods and services, and the effect this has with the supplier.

Note: The bars show the total lifetime impact of projects commissioned in a given decade, e.g., construction plus 25 years of operation.

In terms of local value creation, there is a large difference between CAPEX and OPEX. While the construction of the OWF will take place within a short timeframe, O&M is spaced out over 25 years. Thus, the fewer full-time employees will be needed to deliver the FTEs from O&M compared to construction. The results on local FTEs are summarised in Table 9.6.

TABLE 9.6: LOCAL EMPLOYMENT EFFECT FROM OFFSHORE WIND INVESTMENT.

	Direct FTE	Indirect FTE	Total FTE
Low Growth scenario (500MW)	15,600	9,100	24,700
High Growth scenario (1GW)	36,200	21,400	57,600

Offshore wind requires a considerable input of labor. Installing the first 500MW offshore wind in Sri Lanka will require approximately 24,700 FTE years of labor input. How this equates to jobs depends on the time frame of the project. During construction of the first 500MW offshore wind, Sri Lanka is expected to deliver approximately 5,600 FTEs over the span of the construction phase, estimated at five years. That equates to roughly 1,100 full time jobs. During O&M of the 500MW, Sri Lanka is expected to deliver approximately 9,900 FTEs over the span of 25 years. This corresponds to almost 400 full time jobs. On top of the direct employment from the construction and O&M comes the indirect employment in other sectors. The indirect impact is on a similar scale as the direct impact.

10 HEALTH AND SAFETY

Since the beginning, the offshore wind industry had to deal with various health and safety (H&S) challenges. The supply chain of the offshore wind industry: manufacturing, siting, transport, construction, and maintenance — is different from those of other industries in each step. Challenges in manufacturing and transport arise from the enormous weight and size of the different components. During siting, transport, and construction, the remote location of the sites at open sea with extreme and rapidly changing weather conditions is the main difference to other industries. The enormity of the plants and the unique environmental conditions on the one hand, and the recent formation of the offshore wind industry on the other hand are among the reasons for the ongoing development of specific offshore wind H&S guidelines.

Offshore wind farm construction and operations pose significant H&S risks for (contractor) personnel and should always be handled with great care to create a safe working environment.

10.1 HEALTH AND SAFETY RISKS

H&S risks comprise hazards and activities/operations with potential for dangerous situations. A hazard is a situation or an activity with the potential to harm people, environment, or property. Regarding offshore wind projects, examples of the most relevant hazards and dangerous activities/operations are listed in Table 10.1.

TABLE 10.1: EXAMPLE HAZARDS AND DANGEROUS ACTIVITIES IN OFFSHORE WIND PROJECTS [53].

Hazards	Activities & Operations
WTG access/egress	Transit by air/sea
Working at height	Routine/corrective maintenance
Electrical exposure	Lift/crane operations
Confined spaces	Piling and grouting
Remote working	Cable laying
Manual handling	Subsea operations

The activities undertaken during the construction and operational phases of an OWF will subject the work force to a range of risks which will differ depending on each individual's role. As a result, it is important to understand what these risks are, and assess each one so that they can be minimized, or ideally, completely eliminated. Risks are typically assessed in two dimensions: firstly, the probability of occurrence and secondly, the severity of the associated hazard. The **probability** quantifies the likelihood of a hazard occurring whereas the **severity** is a measure of the amount of damage or harm a hazard could create.

Risk assessment involves a sequence of actions to trace and evaluate the risks associated with the execution of a task. It requires the awareness of all possible events and the detailed knowledge of each step of the process. The result of the risk assessment is usually divided into three risk categories: low, medium, and high. A low risk does not require immediate action. However, a high risk should not be accepted by the employer and should result in the implementation of an alternative method to reduce the risk to an acceptable level.

Risk assessment is an instrument that helps to identify hazards and indicates how to deal with those. An example of a simplified Task Risk Assessment is presented in Table 10.2.

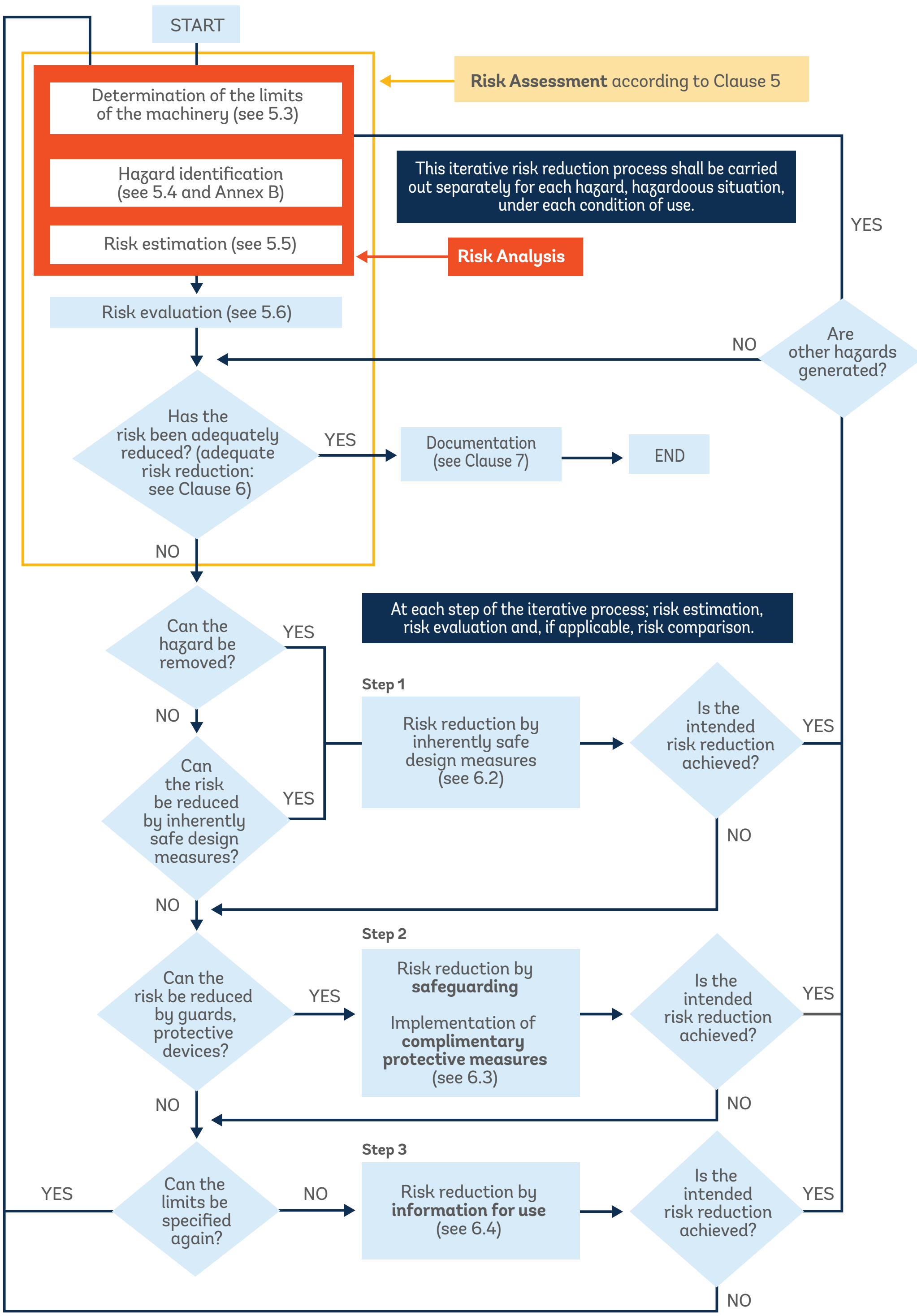
TABLE 10.2: TASK RISK ASSESSMENT.

		Probability of Occurence				
Severity	1	A	B	C	D	E
	2	LOW	LOW	LOW	LOW	MED
	3	LOW	LOW	LOW	MED	HIGH
	4	LOW	LOW	MED	HIGH	HIGH
	5	LOW	MED	HIGH	HIGH	HIGH
	6	MED	HIGH	HIGH	HIGH	HIGH

Probability of Occurence		Severity		Risk	
A	Very unlikely to occur	1	Negligible	LOW	No immediate action required, proceed with care
B	Unlikely to occur	2	Moderate		
C	Might occur	3	Serious	MEDIUM	Review & implement preventive measures
D	Likely to occur	4	Major	HIGH	Unacceptable; find alternative method
E	Will probably occur	5	Catastrophic		

The risk assessment process is usually followed by a risk reduction process, in which protective measures can be implemented to diminish or eliminate the identified hazards. The assessment and reduction processes can be iterative, depending on the time and effort needed to set up an appropriate system to adequately mitigate specific risks. An example of this process is illustrated in Figure 10.1.

FIGURE 10.1: EXAMPLE OF RISK ASSESSMENT AND RISK REDUCTION PROCESS (EUROPEAN STANDARD, 2018).



The first time the question is asked, it is answered by the result of the initial risk assessment.

10.2 INTERNATIONAL GUIDANCE

The following table provides an overview of international organizations that provide H&S guidelines for the offshore wind sector. It includes links to the most relevant online resources.

TABLE 10.3: OVERVIEW OF INTERNATIONAL GUIDANCE ON H&S IN OFFSHORE WIND.

Organization	Description	Online Resources
The Energy Institute	The Energy Institute does not work on H&S guidelines itself but provides an extensive database of resources in the field of H&S in offshore wind projects. The institute is based in the UK and collaborates with The Crown Estate.	The offshore wind collection provides more than 100 guidance documents [54].
European Agency for Safety and Health at Work (EU-OSHA)	EU-OSHA is the European Union information agency for OHS. Its work contributes to the European Commission's Strategic Framework for Safety and Health at work 2014-2020 and other relevant EU strategies and programs, such as Europe 2020.	EU-OSHA has published a few reports including guidelines for the wind sector, including: • E-fact 79: OHS in the wind energy sector [55] • OHS in the wind energy sector [56] • E-fact 80: Hazard Identification Checklist: OHS risks in the wind energy sector [57]
Global Offshore Wind H&S Organisation (G+)	(G+) is an international association based in the United Kingdom (UK) with the aim of creating and delivering world class H&S guidelines for the offshore wind industry. The association has 11 members which are all European utilities.	The G+ has developed a few good practice guidelines and has published these through the Energy Institute. These guidelines provide recommendation for working at height in the offshore wind industry, the management of small service vessels, offshore wind transfer, and offshore emergency response [58].
World Bank, International Finance Corporation (IFC), and Equator Principles Association	International lenders providing financing for infrastructure projects	The General WB/IFC EHS Guidelines contain information on cross-cutting environmental, health, and safety issues potentially applicable to all industry sectors [59]. This document should be used together with the relevant Wind Industry Sector Guidelines [60].
International Marine Contractors Association (IMCA)	An influential trade association with more than 900 members from the offshore marine construction industry worldwide. The organization provides one of the most extensive collections of health and safety guidelines for offshore projects in general, including offshore wind but also offshore oil and gas projects.	HSSE Guidance and Technical Reports can be obtained from the IMCA website [61].
WindEurope	Formerly known as the European Wind Energy Association, which actively promotes wind power in Europe and worldwide. It has over 450 members active in over 40 countries.	WindEurope has a H&S Working Group which aims to promote and share H&S activities, best practices, and lessons learned. They occasionally publish guidelines (e.g., on emergency arrangements including first aid) [62].

A list of some international standards is also provided here:

/EN 50308/	EN 50308:2005 Wind Turbines — Protective Measures — Requirements for design, operation, and maintenance
/EN ISO 12100/	EN ISO 12100:2018 Safety of machinery — General principles for design — Risk Assessment and risk reduction
/ISO 31000/	ISO 31000:2018 Risk Management — Guidelines
/EN ISO 14122-1/	EN ISO 14122-1:2016 Safety of machinery — Permanent means of access to machinery — Part I: Choice of fixed means and general requirements of access
/EN ISO 14122-2/	EN ISO 14122-2:2016 Safety of machinery — Permanent means of access to machinery — Part 2: Working platforms and walkways
/EN ISO 14122-3/	EN ISO 14122-3:2016 Safety of machinery — Permanent means of access to machinery — Part 3: Stairs, stepladders, and guard-rails
/EN ISO 14122-4/	EN ISO 14122-4:2016 Safety of machinery — Permanent means of access to machinery — Part 4: Fixed ladders

A brief description of the most common H&S guideline categories is provided here.

- **Guidance on the investigation and reporting of incidents.** Defines the procedures and formal requirements in a case of an incident. It includes recommendations on interviewing the personnel, inspecting the site, and filing and managing the collected information. It also gives examples for an incident classification scheme and insurance reporting.
- **Marine roles for small workboats.** Aims to provide guidance for the staff of the offshore wind industry operating on small workboats less than 200 gross tonnes. The guidance considers the special requirements and areas of competence of the operation of those small sized vessels. It must be understood as a framework which should be applied with regard to local requirements.
- **Risk assessment.** Provides recommendations for the continuous mitigation and controlling of risks in the offshore work environment. It highlights the importance of communicating information about hazards to reduce injuries of workers or damages of the equipment. The assessment can be conducted via a written document or with the help of a toolbox meeting and covers a wide variety of areas within the offshore operation.
- **Safe lifting.** Sets the guidelines for lifting jobs in the marine environment. As they are a crucial part of offshore operations, the document lays out rules for equipment, maintenance, and safe operation. Besides the theoretical background, a safe proceeding also requires experience and practice.
- **Toolbox talks.** A guideline that gives recommendations for the phase right before undertaking the actual job on the project site. A group talking with focus on the tasks of each team member maximizes the effectiveness and reduces the risk of accidents or delays during the operation. They can take place on a regular basis or at shift change and should follow the four basic requirements of timing, attendance, observation, and knowledge.
- **Working at height.** A guideline initially developed for the offshore oil and gas industry to reduce the number of work-at-height accidents. Besides the discussion of hazards and recommendations for working on a ladder, working on scaffolds, working on platforms or near an open hole, the specific aspects of working in the offshore wind industry were added in the guideline of the G+; for example, access and egress, or transfer between vessels.

10.3 BEHAVIORAL SAFETY

As stated in [27] and [29] behavioral safety covers all non-technical aspects of safety and determines how work is actually undertaken, which sometimes differs from how work is expected to be undertaken.

Analysis of incident data shows that behavioral failures are the most common immediate cause for incidents. This understanding has served as basis for focussing on safe behavior in different industries.

Safe behavior by individuals is defined by the safety culture in an organization. Some of the key factors impacting the safety culture are:

- Management support and involvement in safety
- Management style
- Visible management
- Good communication at all levels of an organization
- Striking the balance between different types of goals — e.g., safety goals and production goals

The management plays a key role in defining and leading the safety culture within an organization.

Working with behavioral safety will require a mapping of the present state in an organization and how employees act at all levels in relation to safety. The mapping can include evaluation of routines, procedures, and attitudes towards safety. Depending on the result of the mapping, specific mitigating actions can be taken to change the behavior if needed. The focus in changing behavior should be on the desired safe behavior and working with barriers to get there. It must be stressed that changing behavior requires involvement from all levels of the organization, as well as strong H&S leadership.

10.4 GWO TRAINING

GWO has introduced a set of training standards for working within the offshore wind industry. GWO training standards are courses that teach to understand and reduce the risk associated with safety hazards in the wind industry. The training standards comprise the following:

- Basic safety training standard
- Lift user training standard
- Basic technical training standard
- Advanced rescue training standard
- Enhanced first aid training standard
- Blade repair training standard
- Slinger signaller/rigger person training standard

A full overview of the standards and the content is available at the GWO webpage: GWO Training Standards (globalwindsafety.org).

Upon completion of the GWO Basic Safety Training (BST) Sea Survival, people will be trained to work on offshore wind installations, e.g., WTGs, construction vessels, accommodation platforms, transformer stations, etc. They will learn personal survival techniques and methods of safe transfer between vessels and installations.

Currently, there are no companies offering GWO courses in Sri Lanka. However, India holds several companies providing certified training.

10.5 OFFSHORE H&S IN SRI LANKA

As the offshore wind sector has not taken off yet in Sri Lanka, there is no specific regulation in place for offshore wind activities.

The overall policy governing health and safety in Sri Lanka is "The National Occupational Health and Safety Policy" [63]. Currently, only guidelines for geophysical, geological, and geotechnical programs related to offshore exploration activities, have been published. Health and safety requirements which should be fulfilled by such programs are briefly described in these guidelines [64].

The National Institute of Occupational Safety and Health (NIOSH) under the Ministry of Labour and Trade Union is responsible for the overall organization of H&S related frameworks and activities at the federal level in Sri Lanka. Their scope of work includes advising the government in formulating national policies on occupational H&S, defining measures for preventing accidents, executing and assisting in surveys, investigations and research in H&S, organizing seminars and workshops in the topic, and establishing national standards, among others.

Furthermore, the Sri Lankan government is currently seeking for improvements on its Monitoring, Control and Surveillance (MCS) system, mainly aimied at addressing issues in its marine fishery sector. In this regard, sea safety is perceived as insufficiently considered in the country. The development of this system and the focus on establishing measures to address sea safety, although initially focused on fishing activities, would consequently bring guidance to the offshore wind sector as well.

Based on the data and findings from the MCS, NIOSH is fundamental in providing some outline and regulation for H&S requirements for offshore wind, such as requirements for H&S organization, risk assessment, control, measurement, and documentation, as well as inspections.

Through the planning of future exploration and extraction of offshore hydrocarbons, PDASL and other government entities are developing new health and safety regulations. It is expected that these will be largely based on the principles employed in the UK and Norway, and that some of these regulations will be applicable to offshore wind activities. This initiative could benefit the development of offshore wind as it would help to educate regulators (and local workers) on the risks associated with the offshore environment, as well as emphasizing the importance of safety while working offshore.

11 GRID INFRASTRUCTURE

Connection to the electrical transmission grid is an essential enabler for offshore wind farms, however grid connection can present some challenges. This section reviews the general capacity of the Sri Lankan grid to absorb electricity from offshore wind farms and opines on necessary measures to enable their grid connection.

Generally, integrating a growing proportion of renewable energy sources into the electrical transmission system may be challenging for a variety of reasons. Most renewable energy sources such as wind are variable, and the energy output depends on the resource quality determined by weather conditions and the time of day and year. The increasing share of VRE in the power system can therefore make power balancing and power grid control more challenging. Flexibility in the generation mix in terms of regulation of power production is to be introduced and provided, both from a technical and a commercial perspective.

The electrical generation/transmission system of Sri Lanka is an island network with no current interconnections to other countries. It has a complex mix of primary energy sources (gas, hydro, coal, oil, onshore wind, and solar) located mainly on the central west coast and in the center of the country.

In 2020, approximately 2GW renewable energy generation capacity was operating in Sri Lanka, including approximately 1.8GW of hydro power [65]. With hydro power being non-variable, the remaining VRE sources (wind and solar) comprised approximately 0.2GW of the total generation capacity in Sri Lanka.

11.1 EXISTING POWER SYSTEM

In 2020, the total installed power generating capacity in Sri Lanka was approximately 4.3GW [66]. Approximately 48 percent of this is renewable energy generation, predominantly hydro power but with wind and solar expected to increase rapidly, according to the long-term generation expansion plan.

11.1.1 Generation

The existing power generating plants (thermal and hydro) in Sri Lanka are shown in Figure 11.1.

FIGURE 11.1: MAP OF SRI LANKA GENERATION PLANT AND THE TRANSMISSION SYSTEM [66].

Most thermal power plants are located close to the large demand center of Colombo, which is also due to Colombo port being able to handle the import of fuel. Many of the hydropower plants are in the central region of Sri Lanka in the hilly areas, accommodating collection of water in larger reservoirs. The northern part of Sri Lanka has very few power plants, which is due to the relatively low load demand in this part of the country.

11.1.2 Transmission

The Sri Lankan transmission system is operated by Ceylon Electricity Board (CEB). The CEB transmission system currently comprises of a 220kV and 132kV transmission network interconnected with switching stations, grid substations, and power stations. The transmission system comprises of 3,090km of transmission lines (including UG HV cable) and 75HV substations. Of the total length, the majority operates at 132kV (approximately 76 percent), whereas the remaining approximately 24 percent, operates at 220kV.

For the transmission network, Figure 11-1 presents the locations and distribution of transmission lines at various voltage levels (220kV, 132kV). Additionally, it also shows that the transmission network is most dense in the center and southwest corner of the island. In the north and east regions, the density of the transmission network is limited, mainly due to low load demand. Basically, and naturally, the transmission system reflects the location of generation capacity as described in section 11.1.1.

Over the coming years, Sri Lanka will look to replace thermal plants due for retirement and introduce more VRE into the transmission system. This, combined with an ever-increasing demand for electricity, means that Sri Lanka will confront an increasing number of challenges in evacuating the power from the new plants. Furthermore, maintaining the generation consumption balance and dealing with potential problems in voltage and frequency instabilities will become increasingly important to manage.

11.2 PLANNED UPGRADES AND EXTENSIONS

It is of paramount importance that the transmission system is developed and strengthened to meet the growing electricity demand in the country.

The necessary transmission system reinforcements to maintain satisfactory power system performance are identified by detailed power system analysis carried out during a long-term transmission development planning process. CEB's long-term transmission development plan (LTTDP 2015-2024) is an updated version of the previous plan (LTTDP 2013-2022), which was designed based on the enhanced version of the long-term generation expansion plan (LTGEP 2015-2034), the divisional MV distribution plans, and the demand forecast.

Specifically, in the five phases of 2015, 2018, 2020, 2022, and 2024, the plan is developed to fulfill each of the network system criteria including voltage, thermal, N-1, security, stability, and short-circuit. As mentioned, in the five phases, the transmission development plan is proposed and, if this plan is implemented as scheduled, the planning criteria will be satisfied so that there would not be any great challenges up until 2024 at least.

11.2.1 Major Identified Transmission Projects

In the development plan for the long-term transmission network system of CEB, the following is the major transmission system reinforcement plan for 400kV and 220kV, proposed for the year 2018 and beyond.

TABLE 11.1: MAJOR DEVELOPMENT PLAN FOR THE 400KV AND 220KV SYSTEM (SOURCE: LTTDP 2015-2024).

Year	Description
2018	**Transmission Lines & Underground Cables** Kelanitissa = Port 220kV cable 6.5km Kerawalapitiya = Port 220kV cable 13.5km Port = Port City 2×220kV cable New Polpitiya = Padukka = Pannipitiya 2×220kV transmission line New Habarana = Veyangoda 2×220kV transmission line Mannar = New Anuradhapura 2×220kV transmission line 125km Nadukuda = Mannar 2×220kV transmission line 30km **New Grid Substations** New Habarana 2×250MVA 220/132/33kV New Polpitiya 2×250MVA 220/132kV Mannar 1×45MVA 220/33kV Nadukuda 2×63MVA 220/33kV
2019	**Transmission Lines & Underground Cables** Kirindiwela = Padukka 2×400kV transmission line (initially 220kV operation) 20km
2020	**Transmission Lines & Underground Cables** New Polpitiya = Hambantota 2×220kV transmission line Veyangoda = Kirindiwela 2×220kV transmission line Kotmale = New-Polpitiya 2×220kV transmission line New Polpitiya =Hambantota (via Embilipitiya) 2×220kV transmission line Pannipitiya = Wellawatta (SubK) 220kV cable Port = Wellawatta (SubK) 220kV cable Sampoor = New Habarana 2×400kV transmission line (initially 220kV operation) 95km **New Grid Substations** Kerawalapitiya 2×45MVA 220/33kV Kirindiwela 2×250MVA 220/132/33kV Hambantota 2×250MVA 220/132/33kV
2022	**Transmission Lines & Underground Cables** Sampoor = New Habarana 2×400kV transmission line (400kV operation) 95km **New Grid Substations** Sampoor 2×500MVA 400/220kV **Grid Augmentations** New Habarana 2×800MVA 400/220kV
2034 (reference)	**Transmission Lines & Underground Cables** Kirindiwela = Padukka 2×400kV transmission line (400kV operation) Padukka = Ambalangoda = Hambantota 2×400kV transmission line

11.2.2 Future Steps Undertaken by CEB for the Trunk Transmission Network System

Based on available information, it is understood that there are major objectives of development in CEB's strategy to fulfill the following operational criteria:

- **Frequency**: 50 Hz± one percent
- **Voltage**: 400kV, 220kV within ±5 percent and 132kV within ±ten percent
- **Fault Current**: 40 kA (220kV and more)
- **Overload**: No overload at N-1 contingency

Moreover, the following have been confirmed in the consultation with the transmission network systems planning division of CEB:

- **Rating Capacity in Normal Operation**: 100 percent
  - in N-1 Contingency: 100 percent
- **Operational Goal for Voltage**: 0.9-1.1 of standard voltage
- **Fault Current**: upgrading to 63 kA in case of surpassing ≥220kV transmission system and 40 kA
- **Dynamic Stability**: Permit generator shedding if dynamic stability cannot be kept

The aforementioned operational criteria (including others) will form the basis for any upcoming master planning of the electrical power systems. Comprehensive power system studies taking into consideration the power grid topology/characteristics, the mix of available generation plants and the load demand for each of the relevant years, will be needed.

11.2.3 Proposed Basic Transmission System Development Plan

The following initiatives are suggested by CEB.

By the Year of 2025

In order to transmit power generated by Sampoor coal-fired thermal power plant a new 400kV transmission line is developed between Sampoor – New Habarana.

To transmit power from renewable energy, such as wind power developed in the north of Kilinochchi, a 220kV transmission line using a large capacity wire between Pooneryn – Kilinochchi – Vavuniya is developed.

By the Year 2030

In order to transmit the power from renewable energy developed in the north of Kilinochchi via the 400kV Sampoor – New Habarana transmission line, a 220kV transmission line using a large capacity wire between Vavuniya – Kappalturai is to be developed. In addition, when wind power generation in the Mannar region is expanded beyond the current 100MW, it will be necessary to examine rewiring of the 220kV transmission line between Mannar – Vavuniya.

A 400kV transmission line is to be newly developed between New Habarana – Kirindiwela depending on the increase in power flow from Sampoor coal-fired TPP and renewable energies in the northern area.

By the Year 2035

In order to transmit the power from renewable energy developed in the north of Kilinochchi, the capacity of the 220kV transmission line between Kappalturai – Sampoor is to be enlarged via rewiring or rebuilding.

In order to avoid a heavy current flow between Vavuniya – New Anuradhapura – New Habarana due to the increase in power transmitted from renewable energy in Kilinochchi, the busbar in Vavuniya is to be separated and the power from Kilinochchi is expected to be transmitted towards only Sampoor.

In addition, since the power flow supplied to the northern part from the Puttalam TPP decreases and the power flow towards the Colombo center increases, as a countermeasure, a line is to be added to the 220kV transmission line between New Chulaw – Veyangoda, or rewiring work is expected to be carried out.

11.3 CONSEQUENCES OF ADDING OFFSHORE WIND POWER PLANTS

Adding offshore wind to the Sri Lanka power system will increase the portion of renewable energy with significant amounts in one step, given the large-scale generating capacity of an offshore wind farm (for example, a typical project size in Sri Lanka could be 500MW). Consequently, an offshore wind farm does not only affect the overall system as such, but also requires specific investigations and most likely upgrades/strengthening at the grid connection point and the immediate back bone system behind.

Furthermore, adding additional amounts of offshore wind may imply that local demand is exceeded. In such case, alternative solutions for use of the energy generated must be considered. For Sri Lanka, two solutions could be relevant: construction of an interconnector with India, and various options for PtX, such as green hydrogen or green fuels.

11.3.1 Transmission System Upgrades/Extensions

Although the plans for upgrading the transmission system as outlined in section 11.2 are significant, adding offshore wind as additional capacity in the magnitude of the growth scenarios (section 6.2) will have a major impact on the transmission system. When assessing the location of the potential offshore wind development areas against the existing transmission network it is evident that most of the areas are not situated close to the large load demand center with a stronger transmission network. Consequently, for development of the areas upgrades and extensions are needed.

The OWF grid interconnection for projects in Sri Lanka is most likely to be 220-275kV AC export system between the wind farm and the point of connection (PoC). Point-to-point high voltage DC (HVDC) systems are now typically used for larger projects (> 1GW) and with large distance between the project and PoC), however this is unlikely to apply to any projects in Sri Lanka (unless a project is combined with an HVDC interconnector with India). Engineering design for a specific OWF project is required to determine the most feasible topology. This offshore export system connection often is a direct transmission link between the OWF and the power grid[64]. Consequently, it is vital to decide who will be the owner and operator of this HV offshore export system transmission. In mature markets, major offshore wind developers have shown a preference to take the design and construction of the offshore export system into their scope, as it allows the developer to better control cost, schedule, and risk. However, this approach is not used in all markets. Different approaches prevail worldwide if the offshore wind developer shall maintain the ownership and operation of this transmission asset or if it shall be transferred to the TSO or a third party. The decision on responsibilities, and the associated legal framework and mechanism to implement the decision, should be settled before a project is tendered to a developer. For further discussion on the different approaches to delivery and ownership of offshore electrical export systems, see section 3.7 of the Key Factors report [17].

For the strengthening and upgrading of the transmission system, it is important that CEB is prepared for the capacity additions and has sufficient time to plan and implement the necessary upgrades/extensions. A high-level assessment of needed upgrades for the three identified areas for potential development of offshore wind is:

- **Area 1 North** – This area is located around the northern part of the country where the transmission network is scarce with only one 220kV line connecting Mannar and one 132kV line connecting Jaffna to the national network. With the large potential in this area, most likely additional substations and transmission lines will have to be constructed to export power to the central part of the country. However, for the first wind farm(s) in the bay of Mannar fewer upgrades/extensions may be needed as the substation and transmission line was recently built and prepared of some capacity additions in this region.
- **Area 2 West** – This area is located close to Puttalam and the central part of Sri Lanka where demand is the largest and where the transmission network is the strongest. However, this area also has the largest power plant capacity, and therefore adding offshore wind will require careful analysis of the existing load and whether the system as it stands is able to absorb additional capacity. Most likely, additional upgrades and extensions will also be required for this area.

64 Shared electrical hubs and offshore meshed grids are being considered in some mature markets with multiple GW and complex developments. This is unlikely to be efficient in Sri Lanka, given the limited capacity to be developed. See Key Factors section 3.7 for further information [17].

- **Area 3 Southeast** – Similarly to the northeast of Area 1, this area is in a part of the country where the transmission network is scarce with only one 132kV line between Hambantota and the central system. CEB has confirmed plans to upgrade the existing 132kV line to 220kV soon, due to construction of additional non-VRE capacity in the vicinity of Hambantota. The new line may have some spare capacity for additional transmission, but given the size of OWFs, most likely more upgrades or extensions will be needed if adding offshore wind in this location.

Any addition of offshore wind in Sri Lanka will require careful transmission planning. Funding will be required for these investigations and to execute the required system upgrades.

11.3.2 Power System Flexibility

Power system flexibility is key when adding significant amounts of VRE. Flexibility can be offered by storage (pumped hydro and battery storage) or by more flexible thermal generation through modernized coal-fired plants, gas-fired power plants, and demand-side response mechanisms. In this regard, Sri Lanka currently has significant hydropower reservoirs which could also add significant flexibility services to the system.

Technical flexibility is closely related to the physical structure of the system. Technical flexibility refers to the combination of technologies that determine 1) the ability of supply to follow rapid changes in net load, 2) avoiding peak demand times (for network benefit) or peak net demand times (for generator), 3) the ability of demand to follow rapid changes in supply, 4) the ability of energy storage to balance mismatches between supply and demand at all time scales, and 5) adequate grid infrastructure to allow least-cost supply to reach demand at all times, anywhere in the power system.

To achieve flexibility in a power system, several steps and actions must be considered.

- **Political level**: Firstly, there must be an active political decision to have an increased share of renewable energy in the energy system along with a legal framework covering establishment of a wholesale market and laying down conditions between TSO and the power generation plants. For Sri Lanka, the decision on increased share of renewable energy in the system all the way up to 100 percent has already been taken. Consequently, it is now a matter of establishing the regulatory framework for implementation of relevant market and technical mechanisms.
- **TSO level**: The second level is the TSO level, which as the dispatcher, is responsible for establishing the wholesale market including the market for ancillary services (frequency support, regulating power, etc.). The TSO should take responsibility for the grid reinforcement in the country which may be a large task since the production of renewable energy is typically located far away from the main consumption of power.
- **Load dispatch level**: The third level is the load dispatch capability, which has to be substantially automated for automatic distribution of load commands to the connected power station units with updated set points every five minutes. The load dispatch is based on optimization of economic parameters and wind forecasts as well as online calculation of the actual flexibility for all thermal power plant units.
- **Plant level**: The fourth level is the plant level. It is important that thermal power plant managers are able to act freely within their economic frame, to be able to implement the required technical solutions and also to accept the increased risks of running more dynamic thermal power plant units.

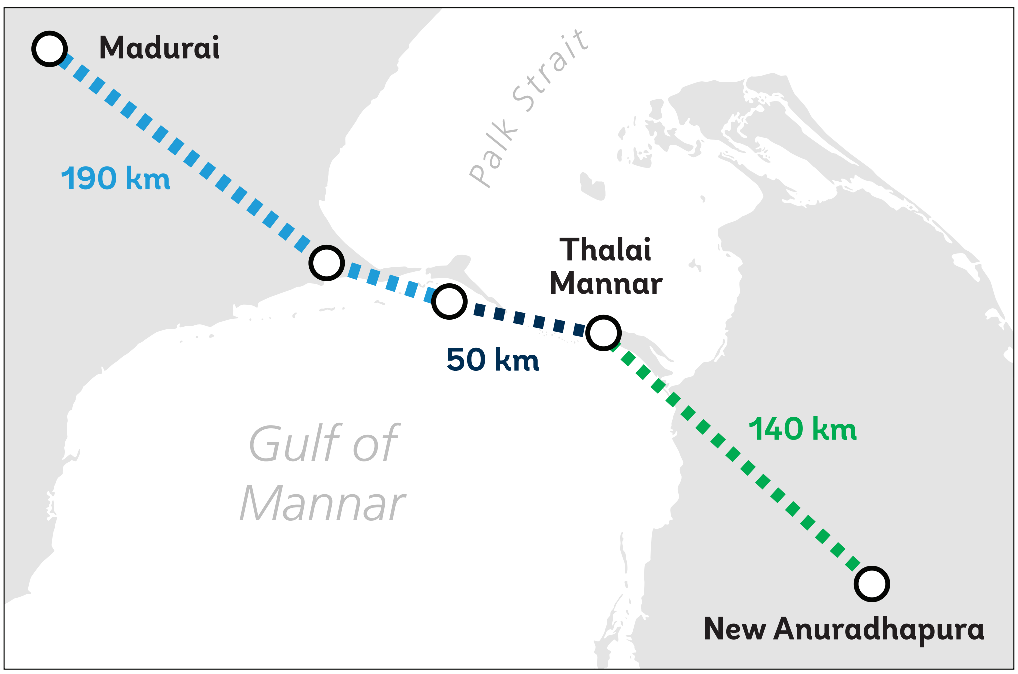
11.3.3 Interconnector with India

For some time, an interconnector between Sri Lanka and India has been discussed. According to a Memorandum of Understanding (MOU) signed between the governments of India and Sri Lanka in 2010, a feasibility study was jointly carried out by CEB and Power Grid Corporation Indian Limited (POWERGRID) for the construction of a 1GW HVDC interconnection project.

Dialogue between the Indian and Sri Lankan governments has recently resumed on the subject of the interconnector and work is underway to further assess its feasibility and options for implementation.

The Sri Lanka — India HVDC Grid Interconnection is a proposed project to link the national grids of Sri Lanka and India. The plan that has been assessed to-date involves setting up a link for 1GW between Sri Lanka and India (in more recent discussions a 500MW option has also been considered). The project involves the construction of a HVDC connection between Anuradhapura in central Sri Lanka and Madurai in southern India, through the Palk Strait. The link would measure 285km in length, including 50km of submarine cables; other somewhat different route options have also been discussed.

FIGURE 11.2: POTENTIAL INTERCONNECTION BETWEEN SRI LANKA AND INDIA [67].

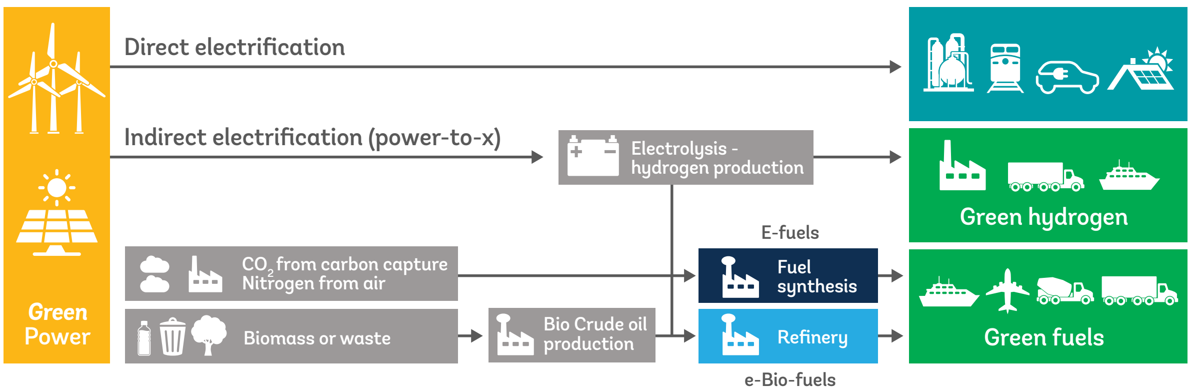


The feasibility study considered the technical, economical, legal, regulatory, and commercial aspects in trading electricity between India and Sri Lanka. While initial studies showed that the project would not be viable [4], more recent assessment by the World Bank shows significant economic benefits. The combined economic benefits for Sri Lanka and India of the interconnection are expected to be very significant both in a short-term analysis (US$326-453 million per year) and a long-term analysis (about US$1.5 billion in discounted terms). Consequently, further studies and most likely adjustments, will be needed in order to fully assess the viability of this project.

11.3.4 Power-to-X

Another possible solution for using and absorbing electricity in excess of domestic demand is to convert renewable electricity into green hydrogen through an electrolysis process, or to other vectors such as green ammonia through other chemical processes. Due to the different array of possible vectors, this is sometimes known as power-to-X (or PtX). It is a fast-growing sector with many potential future applications to enable global decarbonization. Figure 11.3 provides a summary of some of the main pathways from renewable electricity to energy demands.

FIGURE 11.3: A SUMMARY OF THE MAIN PTX TECHNOLOGY PATHWAYS FOR VARIOUS DEMANDS.



Source: COWI

Green hydrogen can be used to fulfill existing hydrogen demands; most often in petrochemical works and the production of fertilizers. Sri Lanka's oil refinery has an existing, small hydrogen demand but there is no other domestic demand.

Green hydrogen can also be converted into ammonia or methanol, and these could have future applications as zero-carbon fuel for shipping. Given Sri Lanka's ready access to passing global shipping fleets as well as the existing traffic using the ports of Colombo and Hambantota, this could provide a new industrial export opportunity for the country.

Although the technology and processes for producing these products is well known and proven, the integration of all these systems at large-scale has not yet been achieved. That said, the green hydrogen sector is expected to develop and mature over the coming decade, and many countries have established ambitious targets. There are currently a large number of green hydrogen demonstration projects, including some using offshore wind generation, being launched in several countries across the globe.

While Sri Lanka's renewable energy resources mean that one day it could generate more electricity than it demands, the business case for PtX applications is not straightforward. High costs and uncertain offtakers are major barriers, but initial pilot projects are being planned in Sri Lanka to demonstrate the technology, potentially leading the way for future larger-scale applications.

Due to the higher cost of electricity from the first offshore wind projects, it is unlikely to be economically viable to use electricity from these projects to produce green hydrogen. As the technology matures and costs reduce — both for offshore wind and green hydrogen — this could be an option to consider in the 2030s or beyond.

12 PORT INFRASTRUCTURE

Like grid infrastructure, port infrastructure is an essential enabler of offshore wind which must be fulfilled locally. In this chapter, Sri Lanka's port infrastructure capacity and capability to support offshore wind is assessed. This chapter focuses on the analysis of potential ports for offshore wind farms, mainly with fixed-bottom foundations for several reasons:

- **Installation ports** for fixed-bottom foundations are an essential enabler for wind farm construction and can act as a key constraint. The installation port is the key port in which main components are received, stored and then shipped to site for final installation.
- **Manufacturing ports** are much more flexible, both in terms of technical requirements and location. Some manufacturing facilities are successfully located inland, while other manufacturing facilities or ports are in other countries. Depending upon the component manufactured, they can have much lower requirements then the construction port. The availability of manufacturing ports does not typically constrain the installation of offshore wind farms.
- **Operation and maintenance ports**, like manufacturing ports, have much lower technical requirements than construction ports. Their location should be as close to the wind farm they serve as possible, but this is not usually a bottleneck, as small regional or even local ports can be used.

The port requirements for offshore wind farms using floating foundations vary greatly according to the technology used, but there are still several design types in use and the industry has not yet converged to one or two commonly used designs. The wide variety of floating technology under consideration at this time does not allow for a quantitative analysis in this study.

It should be noted that potential environmental and social constraints relating to ports have not been considered in the roadmap as this requires a more detailed assessment of upgrades needed. However, any infrastructure project shall of course consider impact on the environment and society.

12.1 INLAND INFRASTRUCTURE

Depending on the offshore wind project, large components may be delivered to the installation port via ship from other ports or, in limited cases, via land routes. The large size and weight of components for offshore wind farms means that it is usually impractical to transport these items over land.

In 2018, Sri Lanka's road infrastructure was ranked at 4.2 out of 7 in the World Economic Forum's survey, putting it at rank 61 out of 141 countries [68]. This indicates that some constraints are expected due to the road network, especially in rural areas. However, such constraints only become relevant in case larger components will be manufactured inland Sri Lanka. Further, it must be noted that all large WTG components and installation cranes for the 100MW Mannar wind farm located on the northwest of the island were shipped to the port of Trincomalee located in the northeast of the island and were successfully transported by road to site. Furthermore, Sri Lanka with its relatively expansive waterfront area, is well positioned to use water transport to the fullest extent possible.

The proximity to other modes of transport such as airports could also be an advantage if crew rotation is planned out of the installation base, and there is an international airport located both in Colombo and close to Hambantota. However, given Sri Lanka's size, this infrastructure is not a driving factor.

12.2 PORT REQUIREMENTS FOR OFFSHORE WIND

Ports are critical infrastructure required for the construction and operation of offshore wind farms. Numerous studies [16] [17] have been published summarizing the typical port requirements, and this subsection provides further information on the main characteristics.

12.2.1 Installation Port Requirements for Fixed Offshore Wind Farms

The port requirements mentioned in this section have been developed with a view to the continually-increasing sizes of WTG components in the 8–15MW range and of the vessels needed to transport and install them. For requirements to which volume is important, such as yard area, the requirements are defined with a typical 500MW wind farm in mind.

- Distance to wind farm
  - A short distance between the wind farm and the installation port allows for efficient use of costly charter vessels and better use of short windows of good weather. Based on a sample of 40 European offshore wind farms, the median distance between the installation port and the wind farm is between 50–100km. Of the 40 wind farms, 36 were within 250km of the installation port. Some outliers, such as Northwind (Belgium) and Westermost Rough (England), where installation was carried out from Esbjerg despite a distance of close to 600km, shows that other factors can take precedence.
  - Maximum: less than 400km
  - Recommended: less than 200km

- Depth at channel entrance
  - The water depth at the entrance, in the channel, or along the fairway should be deep enough to allow access to all vessels at all tides. Having less available depth still allows operations but can pose a limit to larger cargo and installation vessels. Similarly, if a harbour can only be accessed and departed at high tides, this adds additional constraint to a critical activity, which is the efficient charter of installation vessel.
  - Minimum: 9m
  - Recommended: 12.5m

- Harbour entrance width
  - Harbour entry width must be sufficient to allow easy navigation in range of weather conditions. The most constraining vessels are the WTG installation vessels, which often carry blades of over 100m stacked across and protruding from the deck.
  - Minimum: 200m
  - Recommended: 300m

FIGURE 12.1: WTG INSTALLATION VESSEL AT SAIL AWAY FROM HARBOUR, CARRYIN GAT A QUAYSIDE, WAITING TO BE LOADED WITH THE TOWERS, NACELLES, AND BLADES.

Source: Vestas

- Lock/gate
  - Locks are incompatible with cargo that extends over the deck of a vessel, such as is commonly the case with blades on WTG installation vessels.
  - Minimum: No lock or gate present

FIGURE 12.2: BLADES EXTENDING OVER THE DECK OF THE WTG INSTALLATION VESSEL.

Source: Fred Olsen

- Vertical clearance
  - The need for vertical clearance is driven by WTG installation vessels, on which both pre-assembled towers and retracted jack-up legs can extend 100 meters above the deck of the vessel.
  - Minimum: 120m
  - Recommended: No restriction
- Berth length
  - Berth length is a function of the number and length of vessels expected to simultaneously use the berth. Marginal berths (parallel to the shoreline, as opposed to perpendicular) are preferable for offshore wind. Ideally, the berth is marginal (parallel to shore), and two vessels can be moored simultaneously because this gives flexibility in scheduling the inbound and outbound vessels.
  - Minimum: 200m
  - Recommended 400m
- Depth at berth
  - Similar to the depth requirement at the channel entrance, the water depth at the berth must be deep enough to accommodate the common vessels used in offshore wind farms. The slightly lower requirement at the berth is due to smaller under keel clearance.
  - Minimum: 8m
  - Recommended: 12m

FIGURE 12.3: CRANES ON VESSEL LIFTING FOUNDATIONS READY FOR INSTALLATION.

Source: Cadeler

- Load capacity
  - Load capacity describes how heavy a load a certain area can support. The requirement depends heavily on use and type of transport within the staging area. These requirements are driven by the high (and increasing) weights of components such as monopiles, jacket foundations, towers, and nacelles. These components are likely to range from 650–1200 tonnes for 10–12MW WTGs. Increasing the load capacity is one of the most common upgrades required for offshore wind ports. However, this high load capacity does not necessarily need to be present over the whole port area. On a case-by-case basis, it may be possible to have the maximum bearing capacity only in certain areas.
  - In general, having an overall general uniformly distributed load (UDL) of 50kN/m2 is enough to allow both transport and storage of elements such as nacelles, blades, and tower segments.
  - Having a UDL of 100kN/m2 allows unhindered running of all components (including monopiles and transition pieces) using self-propelled modular transporters and staging transition pieces on quay side.
- Yard area
  - To make the most efficient possible use of charter vessels, components are staged in the ports yard area, further away from the quay, and transported in batches to quayside to be loaded as soon as vessels are ready.
  - Minimum: 15 hectares
  - Recommended: 20 hectares

FIGURE 12.4: ESBJERG PORT VIEW FROM THE SVANEN (DENMARK) YARD AREA FOR OFFSHORE WIND ACTIVITIES.

Source: Port of Esbjerg-Christer Holte

TABLE 12.1: SUMMARY OF PORT REQUIREMENTS

Property	Requirement Range (Minimum to Recommended)
Distance to wind farm	<200-<400km
Depth at channel entrance	9-12.5m
Harbour entrance width	200-300m
Presence of lock/gate	Not acceptable
Vertical clearance	120m-no restriction
Berth length	200-400m
Depth at berth	8-12m
Load capacity	50-100kN/m2 (UDL)
Yard area	15-20 hectares

12.2.2 Installation Port Requirements for Floating Wind Farms

Currently, the formulation of a port requirements benchmark for floating foundations is quite an uncertain exercise, as the technology used is still highly varied. The six demonstrator floating wind farms coming online in Europe by 2023, for example, use four different concepts: semi-submersible, barge, tension leg platform, and spar [18]. In time, some of these concepts will emerge as the most popular and then global port requirements can be formulated for them.

Compared to the bottom-fixed foundations, the most important distinction is the absence of the WTG installation vessel with its requirements for an uninterrupted installation schedule. This would result in smaller entrance width and potentially shorter berth requirements.

The key driver of the process would be the production cycle of the floaters which would need to be explored in a detailed planning process. Based on sizes of current demonstration/pathfinder projects, indicative requirements for port properties are described in the following.

The size of storage yard area is unclear as the installation of WTG and floater is a continuous process governed mostly by the rate of floater production. In that sense, the size of the yard could be as low as an area which would allow for one shipload of components to be available for installation (approximately five hectares), but also as high as for bottom-fixed foundations (15-20 hectares).

Load capacity allowance is governed by the heaviest component storage on quay and tracked cranes required for lifting (possibly dual lift). It is therefore likely that requirements are like those for bottom-fixed foundations.

The required depth at berth and entrance may need to be larger than for bottom-fixed foundations, as the foundations are floated directly at quay. While barge-type floaters have comparable draft to vessels used for offshore wind, semi-submersible foundations require larger draft (probably around 20m) for maximal stability.

FIGURE 12.5: WTG MOUNTED ON A SEMI-SUBMERSIBLE FOUNDATION FLOATED DIRECTLY AT QUAYSIDE.

Source: Principle Power

12.2.3 Operation and Maintenance Port

Requirements of ports used for O&M of offshore wind farms are far less demanding than the requirements on ports used for installation. The vessels commonly used for O&M are crew transfer vessels (CTV) and service operation vessels (SOV).

CTVs are small vessels with an overall length of 15-30m and a shallow draft. They are used to reach wind farms which are relatively close to shore and are used for day trips, with the crew returning to shore at the end of the day. To accommodate CTVs, ports need about 4m depth at the channel entrance and berth, a harbour entrance width of approximately 12m, and a vertical clearance of only 10m, as CTVs do not transport large components. When using CTVs, only spare parts and equipment are stored at the port, consequently, a high load capacity is no longer required. An O&M port should ideally have 0.75 to 1.5ha of available area, adjacent to the berthing to allow for the footprint of the onshore facilities, such as offices, storage, accommodation, and workshops. For wind farms served by CTVs, the O&M port is typically located 50-100km from the wind farm.

SOVs are larger vessels with crew lodging and warehousing areas on deck. They can stay at sea for longer periods of time (up to two weeks), making them useful for wind farms that are further from shore or very large. Compared to CTVs, SOVs require deeper (approximately 7m) and longer berth, as well as higher vertical clearance (approximately 40m). As the vessels return to port less frequently, the berth can be shared with other vessels and as some functions are available on the vessel, less yard area could be needed onshore. With an SOV service concept, the O&M port is typically located 100-200km from the wind farm being served.

For large component exchanges or repairs, WTG installation or other specialized vessels may need to be used. However, as these events are infrequent, these vessels can use another port, such as the one used for installation.

12.3 ANALYSIS OF POTENTIAL INSTALLATION PORTS IN SRI LANKA

Sri Lanka has three major potential offshore wind areas: Area 1 (north), Area 2 (west), and Area 3 (southeast). Areas 2 and 3 are more densely populated and thus have a better infrastructure coverage, while Area 1 is more rural. Area 1 also contains Sri Lanka's biggest obstacle to shipping traffic: the limestone shoal formations of Adam's Bridge (see Figure 12.8). This formation is likely the remains of a former land bridge between Mannar Island on Sri Lanka and Pambu Island in India. Though much of the formation is now covered by water, the water depth is not sufficient for shipping traffic to pass through. Adam's Bridge forces ships wanting to circumnavigate India to pass around Sri Lanka, adding significant sailing time. Over the years, many proposals have been put forth by India to create a deep-water canal connecting the Gulf of Mannar with the Palk Strait, some of which cut though Adam's Bridge. The newest proposal, the Sethusamudram Ship Channel Project, is heavily opposed and bogged down in legislation in the Indian courts [69].

As the offshore wind volumes expected in Sri Lanka by 2030 are moderate, it is likely that one major offshore wind installation port in total would suffice. However, it must be noted that with only one port, projects in the area(s) further away from this port will experience higher logistical costs. Due to the anticipated moderate volume of offshore wind expected, it is also important that any upgrades made to the ports for offshore wind are also designed with a multi-functional use. The upgrades should not serve offshore wind alone, but also give an added value to the port between offshore wind installation cycles.

Sri Lanka has four major ports – Colombo, Galle, Hambantota, and Trincomalee – and three minor ports – Kankasenuthurai, Point Pedro, and Oluvil. Of the minor ports, Oluvil and Point Pedro are not further considered in this study. Oluvil is currently out of use due to accumulation of sand blocking the port entrance and Point Pedro is a local port which does not have any usable infrastructure for offshore wind installation.

The following sections present a high-level analysis of each port.

12.3.1 Colombo

The port of Colombo is Sri Lanka's largest and busiest port and is a major transhipment hub of regional importance between the Mediterranean (via the Gulf of Suez) and Southeast Asia [70]. The port has undergone previous expansions to meet increasing demand and is currently in the midst of an extensive development initiative called the "Port City Colombo." This development is on 269 hectares of reclaimed land south of the current port as can be seen in Figure 12.6. It is planned to be a special economic zone, which will combine business interests and living space once complete [71].

FIGURE 12.6: OVERVIEW OF THE PORT OF COLOMBO [72].

While Colombo is technically capable of functioning as an installation port for offshore wind, its position as a major global container transhipment hub may prove to be the biggest obstacle. For a port like Colombo that is operating at capacity, offshore wind could present challenges which would not manifest themselves if the port was to simply continue with its current and main line of business. Firstly, minor upgrades would need to be done on and around the port itself, disrupting the normal business during that time. Secondly, a large laydown area will need to be repurposed from its current use (likely container storage/staging), representing further business disruption. Whether this is economically feasible for the port will depend on the number of wind farms it can serve, their timing, and the project economics. Table 12.2 summarizes how Colombo port measures up against the benchmark given in Table 12.1.

TABLE 12.2: GAP ANALYSIS OF COLOMBO PORT.

Property	Port Gap Analysis
Distance to OWF	The part of Area 1 south of Adam's Bridge is within range. Area 2 is very close: 50km and 100km from port. Approximately half of Area 3 is within 200km.
Depth at channel entrance	OK
Harbour entrance width	OK
Presence of lock/gate	OK
Vertical clearance	OK
Berth length	OK
Depth at berth	OK
Load capacity	Unknown, but likely within required range
Yard area	OK, assuming availability
Conclusion	**Suitable, with minor upgrades and assuming yard area can be made available**

12.3.2 Galle

Galle was an important commercial port in Sri Lanka until 1873, when an artificial harbour was built in Colombo and commercial traffic shifted there. Today, Galle is located in a popular tourist area and yachting destination. Further developments for the port are planned in order to better serve this sector, including the addition and improvement of facilities for passenger vessels, such as yachts, whale watching, and coral watching operators [74].

Galle is considered unsuitable for offshore wind installation due to some key technical factors, such as inadequate berth length and laydown area, but also due to the fact that the heavy commercial shipping and construction operations needed for offshore wind are not seen as compatible with Galle's intended development as a yachting destination. Further, there are potential areas of sensitive coral in the vicinity as well as the Rumassala Sanctuary to consider. Table 12.3 summarizes how Galle port measures up against the benchmark given in Table 12.1.

TABLE 12.3: GAP ANALYSIS OF GALLE PORT.

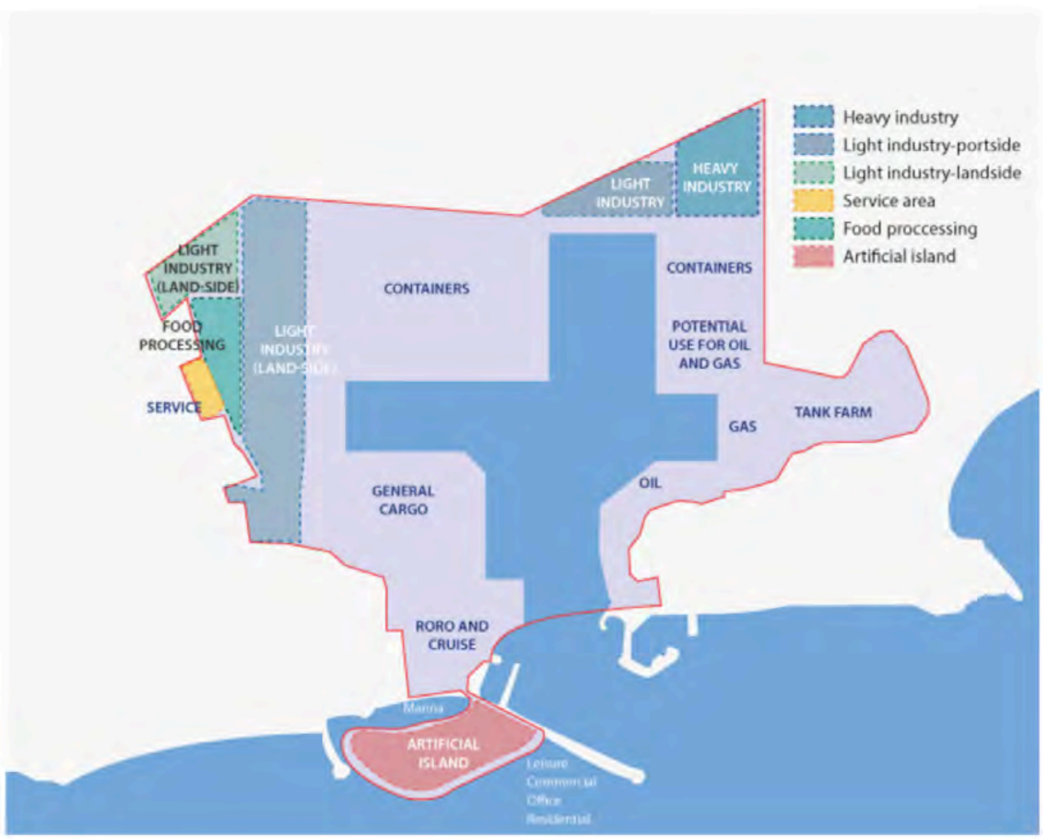
Property	Port Gap Analysis
Distance to OWF	Area 2 and Area 3 can be easily reached within 200km, as well as the western part of Area 1 within 350km.
Depth at channel entrance	Unknown
Harbour entrance width	OK
Presence of lock/gate	OK
Vertical clearance	OK
Berth length	40m less than minimum requirement
Depth at berth	Unknown, but likely not within required range
Load capacity	Unknown, but likely not within required range
Yard area	No available yard areas: all adjacent land is densely developed
Conclusion	**Not suitable**

12.3.3 Hambantota

Hambantota International Port is Sri Lanka's newest major port and is strategically sited close to important east-west shipping routes. It is the second largest port in Sri Lanka and is jointly operated by the Sri Lanka Port Authority and China Merchants Port.

Whereas Colombo port focuses on containerized cargo, the concept for Hambantota was designed to include a wider range of cargo types and services, including an expansive area reserved for industrial use, mostly for light industry, but also with some space for heavy industry, as shown in Figure 12.7 [74].

FIGURE 12.7: HAMBANTOTA PORT PLANNED INDUSTRIAL AREAS [78].



The port has been designed to accommodate the largest container ships and will be suitable for the vessels needed for offshore WTG installation. As vessel traffic is lower at Hambantota than Colombo, the port may be better suited for use as a wind farm installation port. Table 12.4 summarizes how Hambantota port measures up against the benchmark given in Table 12.1.

TABLE 12.4: GAP ANALYSIS OF HAMBANTOTA PORT.

Property	Port Gap Analysis
Distance to OWF	All of Area 3 is within 200km, and Area 2 is within 300km.
Depth at channel entrance	OK
Harbour entrance width	OK
Presence of lock/gate	OK
Vertical clearance	OK
Berth length	OK
Depth at berth	OK
Load capacity	Unknown, but likely within required range
Yard area	OK, assuming availability
Conclusion	**Suitable, with minor upgrades and assuming yard area can be made available**

12.3.4 Trincomalee

Trincomalee is a very large natural harbour in which various terminals are located. Of these terminals, the Ashroff Jetty comes closest to fulfilling the requirements for offshore wind. This terminal was recently used to transport components to the 100MW Mannar onshore wind farm []. To serve as an offshore wind installation port, this terminal would need major upgrades to the jetty itself and to the yard area. The perpendicular orientation of the jetty constrains its use for offshore wind because components must be transported individually down the road to the jetty, which creates a bottleneck. This area would need to be expanded significantly to make efficient component handling possible. A yard area would also need to be created adjacent to the port which is sparsely developed. These developments would be subject to an appropriate ESIA to understand the potential impacts on the natural and human environments. Table 12.5 summarizes how Trincomalee port measures up against the benchmark given in Table 12.1.

TABLE 12.5: GAP ANALYSIS OF TRINCOMALEE PORT (ASHROF JETTY).

Property	Port Gap Analysis
Distance to OWF	Northern part of Area 3 is at the edge of the port's 200km range. The eastern part of Area 1 is well covered, mostly within 200km.
Depth at channel entrance	Unknown
Harbour entrance width	OK
Presence of lock/gate	OK
Vertical clearance	OK
Berth length	Length is ok at 240m, but jetty configuration places large constraints on use
Depth at berth	OK
Load capacity	Unknown
Yard area	No available yard area.
Conclusion	**Suitable with major upgrades**

12.3.5 Kankasenuthurai

In its current form, Kankasenuthurai port is not suitable for offshore wind installation. However, development is underway to improve the port and due to be finished in 2023 [76]. These developments, which are analysed in Table 12.6, go a long way towards closing the suitability gap, but the port would still require major upgrades to the yard and dredging of the channel entrance after these developments are complete.

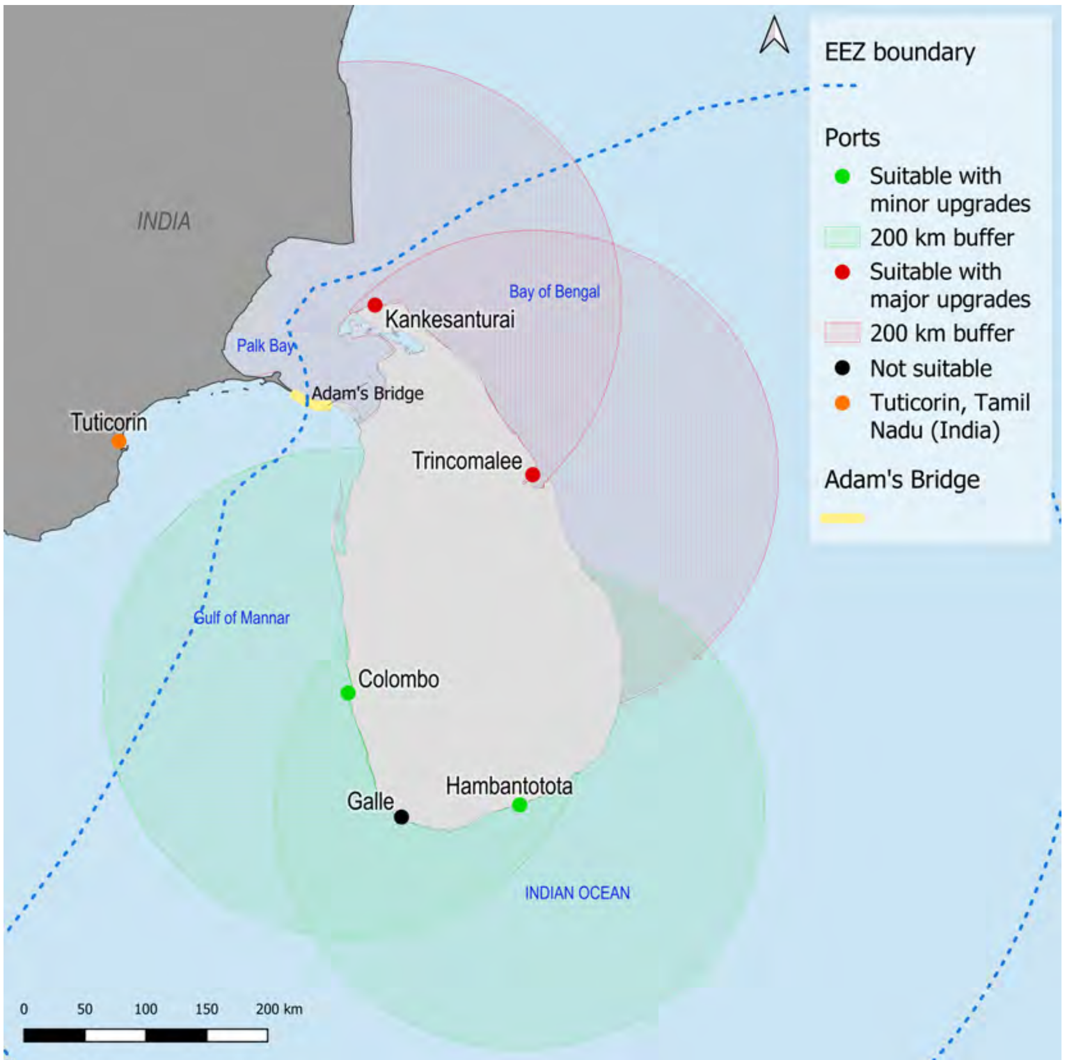
TABLE 12.6: GAP ANALYSIS OF PORT OF KANKASENUTHURAI (AFTER COMPLETION OF PLANNED DEVELOPMENTS).

Property	Port Gap Analysis
Distance to OWF	Almost all of Area 1 north of Adam's bridge can be covered.
Depth at channel entrance	Slightly too shallow
Harbour entrance width	Unknown
Presence of lock/gate	OK
Vertical clearance	OK
Berth length	Very slightly less than recommended
Depth at berth	OK
Load capacity	OK
Yard area	No available yard area
Conclusion	**Suitable after planned development and additional major upgrades**

12.4 SUMMARY MAP

Figure 12.8 shows the location and suitability of the candidate ports, together with 200km range rings and Adam's Bridge. The range rings are shown as an indication of the ideal range of each port but should be viewed as a rough guide.

FIGURE 12.8: LOCATION OF POTENTIAL PORTS, INCLUDING 200KM RADIUS, AND ADAM'S BRIDGE.



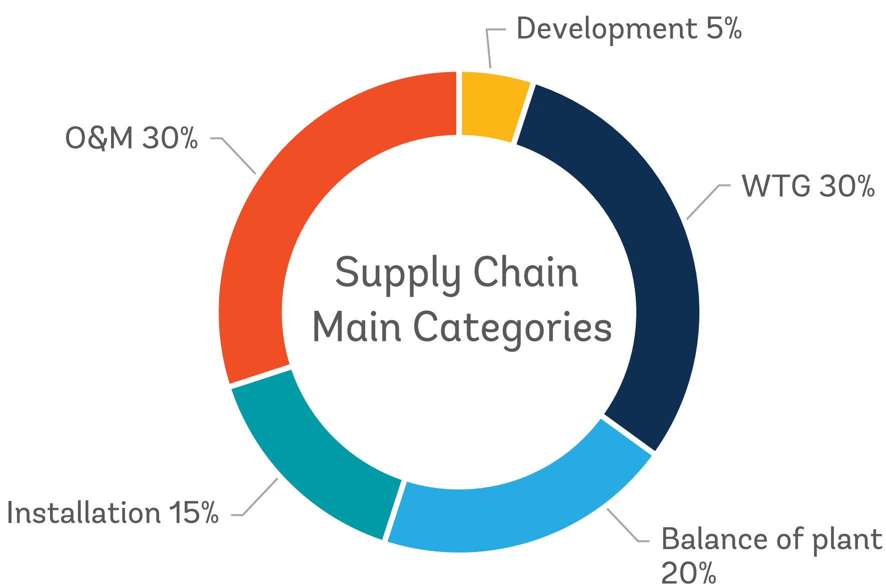
In addition to the Sri Lankan ports, Tuticorin port in India could potentially be used as an installation port [16]. This port should be considered in relation to a possible build-out of offshore wind in Tamil Nadu and, as such, it could also serve development of OWFs in Sri Lanka, especially to the south of Mannar Island or off Puttalam. The use of Indian ports would reduce the potential income opportunity for Sri Lankan ports and local supply chain, but could also reduce the overall cost of offshore wind in Sri Lanka as it would avoid the expense of upgrading local ports.

13 SUPPLY CHAIN

Building an offshore wind farm is a major endeavor and the supply chain required to deliver the material and workforce for such a task is a huge undertaking. This section explores more generally the components and supply chain needs and the potential for Sri Lanka to contribute to each. The procurement list for an offshore wind farm is extensive and makes use of elements from both onshore and marine industries. Supplying an offshore wind farm requires highly specialized technologies like underwater high voltage (HV) cables, as well as heavy engineering elements such as concrete structures and steel frames.

The offshore wind supply chain comprises five main categories as presented in Figure 13.1.

FIGURE 13.1: DISTRIBUTION OF SUPPLY CHAIN MAIN CATEGORIES ON OVERALL COSTS AS A PERCENTAGE OF LCOE OVER A PROJECT'S LIFE [49].



Source: BVG Associates

This section presents an overview of the possibilities related to the offshore wind supply chain in a Sri Lankan context. The different supply chain categories are described and possibilities for Sri Lanka to tap into the supply chain are assessed. The development of a local supply chain, however, is a long-term effort and will occur simultaneously with skill-building, and knowledge transfer over many years. Accordingly, the supply chain items described in the following sections will only gradually migrate to Sri Lanka over time. It must however be noted that given the small size of the electricity market, Sri Lanka will also need to position itself to support Indian offshore wind growth and possible export to other international offshore wind markets. The development of the Sri Lankan supply chain will depend greatly on the success in supporting export markets, with local supply chains in Sri Lanka only evolving to meet the needs of other countries. This is currently a challenge, because Sri Lankan exports are not aligned in size or content to realistically support the needs of large-scale offshore wind development, whereas European countries and India have supply chains that aligned with the needs and scale to support both global and regional offshore wind.

13.1 SUPPLY CHAIN CATEGORIES

The following section explores the key elements and components required for developing a future offshore industry in Sri Lanka. Each category of the needed supply chain is presented, along with a listing of key subcomponents and their relevant international and local providers. In addition, the current market state-of-play is described along with expected upcoming developments.

While project development tasks and survey activities are paramount for establishing a robust wind farm design and realizing a low LCOE, development expenditures (DEVEX) account only for around five percent of the total project expenditure. Hence, capturing most of the project value in Sri Lanka relies on capturing other aspects of the project, e.g., manufacturing, installation, and O&M constituting 95 percent of the overall costs.

The following major component categories have been identified and examined in this study:

- Development
- WTG
    - Blades
    - Nacelles, hubs and assembly
    - Towers
- BoP
    - Foundation supply
    - Array and export cables
    - Offshore substation supply
    - Onshore infrastructure
- Installation
- O&M

FIGURE 13.2: KEY ELEMENTS OF THE OFFSHORE WIND SUPPLY CHAIN.

Source: COWI

13.2 DEVELOPMENT

As there have been no offshore projects in Sri Lanka, there is little experience in the country with the development and permitting issues related to the design, construction, and installation of offshore wind farms. These issues are generally highly important for developers when entering a new country, and developers dedicate significant resources to understanding and navigating local approval processes, permits, and environmental, maritime, and safety regulations.

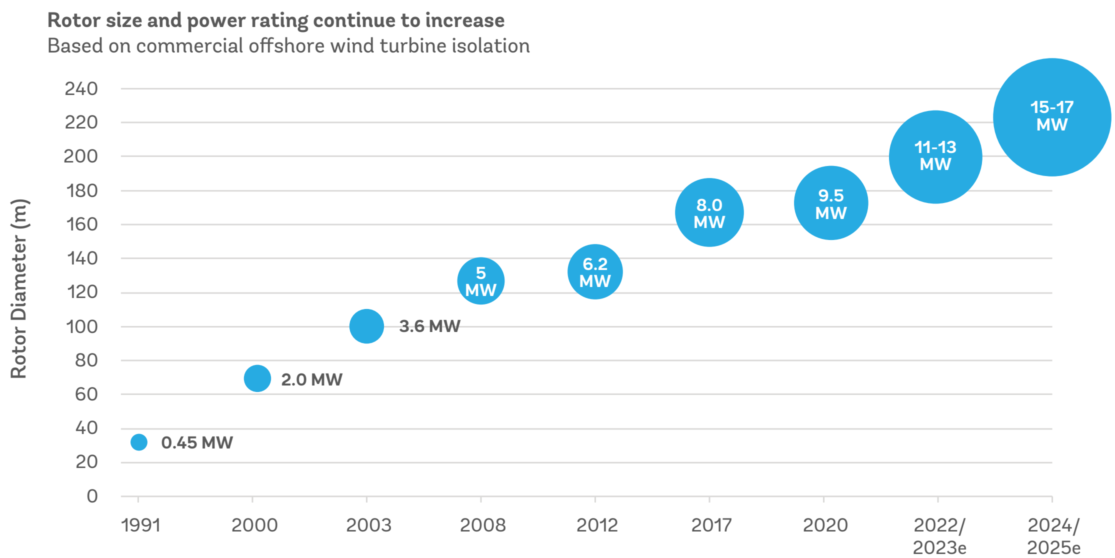
International developers are very cautious towards new markets, perceiving them as high risk. Experience shows that the development cycle for an offshore wind farm can be seven years or longer, and the development and permitting can easily account for half of this time. To help mitigate and manage the risks imposed by navigating unclear and untested development procedures and the supply chain localization requirements often imposed in new markets, international wind developers often partner with local firms that can provide knowledge and insight. Building lasting relationships and partnerships with governments and permitting bodies, and local companies is a key strategy for developers in derisking their projects, even more so in markets that have high-growth targets where multiple projects are ongoing simultaneously. A common practice is to form joint ventures to spread risk. One approach is for an offshore developer to partner with a competent local provider for the onshore infrastructure and grid upgrades.

Joint ventures and other ways of mitigating risk exposure are necessary for offshore wind developers, because developments in other offshore wind markets, like Taiwan have shown that offshore wind tariffs can fluctuate with political cycles, and expose a project to large financial strain. This can delay, or in extreme circumstances, kill a project. Local development partners who can facilitate closeness to regulators are a key asset to a project, as they can help explain the concrete impacts of abstract regulations. Local companies such as WindForce and LTL Holdings are local EPC contractors that have built up project development expertise. While there is currently no offshore wind permitting procedure in Sri Lanka, these local resources could prove essential in driving the development forward within the country.

13.3 WIND TURBINE GENERATORS

At the beginning of the development of the global offshore market, the industry applied onshore WTGs adapted for the marine environment. Since then, the offshore wind industry has advanced significantly and developed into an independent sector that is developing and implementing fast-evolving technologies. Modern WTGs are specifically designed for the offshore environment and would not be feasible for installation on onshore sites. Offshore WTGs are now engineered to cope with the harsh marine environment, including strong wave loads and corrosive saltwater, and are increasingly being adapted to withstand typhoon conditions. Wind farms are built for lifetimes of 25+ years, and new O&M concepts are being explored and designed to reduce maintenance costs and improve reliability over the life of the project. In recent years offshore WTGs have dramatically increased in size (both in terms of rotor diameter and power capacity) and the trend is expected to continue (see Figure 13.3).

FIGURE 13.3: EVOLUTION OF WTG SIZE. SOURCE: GWEC [77].



Source: GWEC Market Intelligence. July 2021

Initially driven by significantly higher investment costs and followed by recent market consolidation developments in the last five years, the number of original equipment manufacturers (OEMs) for offshore WTGs is considerably smaller than the amount of onshore WTG suppliers. Three major western players dominate the global market: the Danish supplier Vestas, the German-Spanish group Siemens Gamesa (SGRE), and American supplier GE Renewable Energy. Within the Chinese offshore sector, the four significant suppliers are Goldwind, SEwind (Shanghai Electric), MingYang, and Envision, jointly controlling over 90 percent of the Chinese market. However, these companies have not established significant market shares outside of China, and SGRE and Vestas are expected to control around 60 percent of the global market share by 2023 [78].

Table 13.1 lists the three leading manufacturers in the international offshore market, including the current WTG types and their size and capacity, as well as the types announced to be available soon.

TABLE 13.1: OVERVIEW OF CURRENT AND FUTURE OFFSHORE WTG MODELS.

Manufacturer	WTG Model	Capacity	Rotor Size	Serial Production (est.)
Siemens Gamesa	SG 14-222 DD SG 11.0-200 DD SG 8.0-167 DD	14MW 11MW 8MW	222 m 200 m 167 m	2024 2022 Currently ongoing
Vestas	V236-15MW V174-9.5MW V164-9.5MW V164-10MW	15MW 9.5MW 9.5MW 10MW	236m 174 m 164 m 164 m	2024 Currently ongoing Currently ongoing Currently ongoing
GE	Haliade-X	12MW 13MW 14MW	220 m 220 m 220 m	2022 2022 2022

None of the offshore WTGs in Table 13.1 have yet been manufactured or installed in Sri Lanka, and Sri Lanka has no manufacturing for onshore or offshore WTGs. However, neighboring India has already built a strong production market for onshore WTGs and has the fourth largest base of wind power installed globally [79]. India has numerous production facilities for WTG components including blades and nacelles. All three leading offshore OEMs (ref. Table 13.1) have established manufacturing facilities in the country for their onshore WTG portfolio or work with local production partners for the production of components [80] [81] [82]. It is likely that even if there is a significant pipeline of offshore projects in Sri Lanka, the investment risk may be too substantial to invest in Sri Lankan factories, because even in the event of a high growth scenario for offshore wind, manufacturing supply chain investments are likely to remain elusive, as these will gravitate to the larger Indian market. A fully-developed Indian offshore wind market will easily be able to handle production and transportation of large offshore WTG components to serve the smaller Sri Lankan market.

A further challenge for the advent of the Sri Lankan offshore WTG supply is that current-generation offshore WTGs are designed for a high-average, high-extreme wind speed regimes. However, Sri Lanka presents a wind regime with lower average wind speeds. Utilizing smaller WTGs increases the number of WTGs, and foundations necessary to design, transport, install, and maintain, thus making it challenging to lower the cost of energy via economies of scale. However, even utilizing smaller WTGs would not provide a significant boost to local content production in Sri Lanka, as there are no existing onshore factories suppporting WTG production. These supply chain benefits would gravitate to India.

13.3.1 Blades

One of the main components of a WTG is the rotor and, more specifically, its blades. These dictate the energy capture, transforming the energy inherent in the wind flow into rotational torque, which is subsequently converted to electrical power using a generator.

In recent years, the offshore wind market has seen an astonishing increase in blade span. While in 2017, a 5MW WTG presented blade lengths of around 60-70m and had rotor diameters of approximately 130m, modern WTG models have increased their blade lengths up to 107m [83], manufactured by GE subsidiary LM Windpower. GE has applied these blades on its Haliade-X prototype, which has been erected on a test site in the port of Rotterdam and is currently producing power. The huge blade size not only requires highest technical design and fabrication capabilities, but it also imposes constraints for transportation and installation.

Over the years, WTG blades have been mainly produced from glass fiber-reinforced polyester or epoxy. Newer materials like carbon fiber have been considered for production due to their high rigidity and strength as well as lower weight. However, since the material is expensive and difficult to work with its use has been mainly restricted to the supporting laminates.

FIGURE 13.4: BLADES READY FOR TRANSPORTATION AT THE PORT.

None of the big three offshore WTG manufacturers have blade factories in Sri Lanka, and it is highly unlikely that they will establish these facilities in the future. However, all three have established in-house capabilities in India [84] [85] [86], which would likely adapt their factories to handle offshore wind growth in the region.

13.3.2 Nacelles, Hub, and Assembly

Major WTG components such as the rotor hub, nacelle, gearbox, and bearing housing require large steel castings, while gear wheels, bearing rings, bearings, shafts, and tower flanges require steel forgings. Only a limited number of European foundries can cope with the required size to cast these components. Examples of established suppliers are Brueck, Euska, Fonderia Vigevanese, Siempelkamp, Torgelow, and VTC.

Sri Lanka currently has a foundry industry that could support some smaller components that go into the production of the rotor-nacelle assembly; however, it is unlikely that larger castings and components could easily be tackled by current market participants [87], who are focused on residential and light engineering products.

FIGURE 13.5: VESTAS V236 15MW PROTOTYPE NACELLE.

Source: Vestas

When the long blades of an offshore WTG transform the wind's kinetic energy into rotational movement, they create a tremendous amount of torque on the main shaft of the drive train. The gearbox is then in charge of converting this high torque into a lower torqued, high-speed shaft that drives the generator. Given the logistical challenges and high maintenance and repair costs at sea, offshore gearboxes are expected to be highly robust and reliable and are one of the most mechanically advanced components of a WTG.

Compared to the 3-speed gearbox variants commonly found in the onshore wind industry, offshore WTGs have turned into mid-speed and direct drive options, a trend that is likely to continue. Most recently, digital hydraulic drive train options are also being tested. The electric generator concludes the energy conversion by transforming the mechanical energy into electrical energy, subsequently discharged to the grid. In the offshore wind industry, gearless, direct-drive solutions and drivetrains consisting of gearboxes with permanent magnet generators have proven to be the most cost-effective and technically reliable option. As a result of the different technical approaches to drive train solutions, this component has become increasingly product-specific, leading to implications for supply availability as the establishment of a new supplier for such subcomponent requires significant lead time. As the size of future generation gearboxes and mid-speed or direct drive generators continues to increase, developers will prefer coastal sites located close to nacelle assembly facilities.

Suppliers like Winergy, Bosch Rexroth, and ZF Wind currently serve the European market; however, Vestas is the only European manufacturer that uses a gearbox for their offshore WTGs, limiting the potential for European gearbox suppliers in Sri Lanka. In addition, these companies are already established in Indian market, and are not likely to set-up factories to specifically service the Sri Lankan market [88] [89].

13.3.3 Towers

The towers for offshore WTGs are very similar in composition as those for onshore sites. However, due to the harsh environment, the towers also have higher quality requirements (e.g., anti-corrosion coating) than towers for onshore WTGs. Accordingly, potential suppliers must undergo a higher qualification process during selection by the OEMs.

Similarly to the WTG blades, the towers for offshore WTGs have particular logistical requirements. For example, the wider base diameter of the towers might easily exceed the traffic underpass requirements. WTG types, such as the V164-8.0MW from Vestas, use a tower base diameter of 6.5m. Therefore, the manufacturing facilities are expected to be located near the coast and in close proximity to the projects to tackle logistical constraints.

As WTG sizes continue to increase, the increase in wind farm size has not translated proportionally into an increase in tower demand. When using a 15MW WTG, a 1GW wind farm installation will require 67 towers instead of 160 needed for a smaller 6MW WTG. With the trend towards larger structures, smaller numbers of towers will be produced and may pose challenges for developing an offshore tower facility without a sufficiently large pipeline. This dilemma is at the heart of the puzzle that governments must solve in order to attract the much-desired offshore wind manufacturing industry jobs, which will not happen without building a significant pipeline. As a guideline, manufacturers might require an output level of 100-200 towers per year over a period of five years to justify investment in a new factory. Accordingly, tower suppliers should expect to supply two or more WTG manufacturers to support the investments they will need to make confidently. However, the high transferability of offshore WTG manufacturing might mitigate this risk, and new coastal facilities could also serve onshore wind tower demand.

European tower suppliers like Welcon or Titan Wind Energy (Europe) and Chinese suppliers like CS Wind or Titan Wind (Asia) will probably not find much potential to do new business in tower production, as this is a relatively low-tech, low added-value component with mature manufacturing. The offshore production might well be served by current onshore tower manufacturers in India but is not likely to be easily established in Sri Lanka.

13.4 BALANCE OF PLANT

BoP refers to various supporting and auxiliary components of an offshore wind farm, exclusive of the WTG supply. This includes WTG foundations, and electrical infrastructure, both offshore and onshore (cables and substations).

13.4.1 Foundation Supply

The foundations on which offshore WTGs are installed have historically been fixed to the seabed. Lately, the development of floating foundations has taken off, but the technology is still in the early-development stage, and only a few demonstration/pre-commercial projects have been deployed worldwide.

Within the group of fixed foundations, three main types exist — gravity-based concrete foundations for shallow waters, steel monopiles for water depths of 20m-50m, and steel jackets for deeper sites up to 60m. Given the lower cost and simple design, the vast majority of the installed European offshore wind projects rely on steel monopiles and jacket structures, with some near-shore projects utilizing gravity-based concrete foundations. However, an emerging interest in gravity-based foundations has been observed, mainly due to simplified installation and manufacturing, although the size of the foundations needed for modern offshore WTGs now means that the size of the foundations is becoming a limiting factor in their production. Thus, the choice of foundation is closely linked to the site properties (i.e., water depths, type of seabed, and wave loading) and the WTG size, but the local fabrication and installation capabilities also play an essential role.

Gravity-Based Concrete Foundations

Gravity-based foundations are large, reinforced concrete structures that do not require piling. Instead, they have a significant footprint (>30m in diameter) and rely on their weight to resist overturning. Two major types of designs exist and rely on different installation methods. The first design type is a non-buoyant foundation, which allows the pre-installation of the WTG on top of the foundation quayside. For installation, the whole structure can be transported to the site employing a heavy lift crane vessel. The second alternative is a buoyant design, which can be towed to the site and then ballasted with sand and water to sink the structure to a prepared location on the seabed. The WTG and tower are then installed onto the foundations thereafter. Note that in the case of floating gravity foundations, the WTG and Tower may be installed at the quayside before floating out to the site. This removes the need for a heavy lift jackup vessel for the WTG and Tower installation, which can sometimes be a bottleneck due to conflicting requirements from other windfarm installation globally.

Gravitas (Arup), BAM, and Van Oord are three suppliers currently working on the buoyant concepts, while Boskalis or GBF, a consortium of Ramboll, Freysinett, and BMT have focused on the non-buoyant approach. With a weight exceeding 3,000 tonnes, and a much heavier weight for a filled, buoyant design, gravity-based foundations are the preferred foundation on shallow, calm waters and well-sedimented seabed. They have been mainly installed in the Baltic Sea (e.g., at Kårehamn in Sweden). New hybrid concrete-steel designs promise to make gravity-based foundations applicable in harsher and deeper environments; however, none of these have been applied yet at full scale in commercial projects.

Gravity-based foundations do not require piling but are mainly applicable on sites with rock-headed seabed. Their installation on exposed, deeper waters like the North Sea is difficult, however. In Sri Lanka, it is likely that the use of gravity-based foundation technologies would require significant port upgrades, as storage will likely exceed the bearing capacity at Sri Lankan ports due to the enormous dimensions and weights of these structures. Sri Lankan construction companies such as Access Engineering may be interested in the construction of these foundations for the Sri Lankan market.

Monopiles

Monopiles are large tubular steel structures, which are currently up to 80m length. They consist of tubular sections rolled out of steel plate and then welded together. Once transported to site, the installation crew typically drives the monopiles into the seabed with a hydraulic pile hammer, or pre-drills the pile before hammering if soil conditions are challenging. A transition piece (TP) is then added, which is mounted on top of the monopile and grouted or bolted into position. The WTG tower is then bolted to the transition piece, which helps to level tower, acts as an attachment point for boat landings, access ladders, and work decks.

Monopiles have long proven themselves in the industry as the most cost-effective solution for offshore wind. The technology is tried and tested for even the largest WTGs on the market, and projects with water depths of 40+m are using or considering monopile foundations. The success of the monopile foundation is primarily due to its simplicity, which has allowed for fast evolution as the ability of manufacturers to retool factories to handle increased steel thickness and diameter has increased. In 2012, a diameter of 6m was considered the maximum, which increased to 9m by 2015. In recent years however, the industry has pushed this boundary even further and now diameters of up to 11m with a thickness of 150mm and achieving total weights of up to 2,000 tonnes have been possible. Major player SIF has been able to provide these capabilities since 2017, and in 2019, the German manufacturer Steelwind Nordenham also finalized the supply of 40 monopiles with this diameter for the Taiwanese Offshore wind farm Yunlin. Further established market suppliers are Bladt, EEW SPC, and Bilfinger (now part of the VTC Group).

Currently, the largest monopiles being designed in the EU will not immediately be provided by Sri Lankan suppliers, with Indian or European suppliers rolling the monopiles for Sri Lankan projects in an either low or high growth scenario.

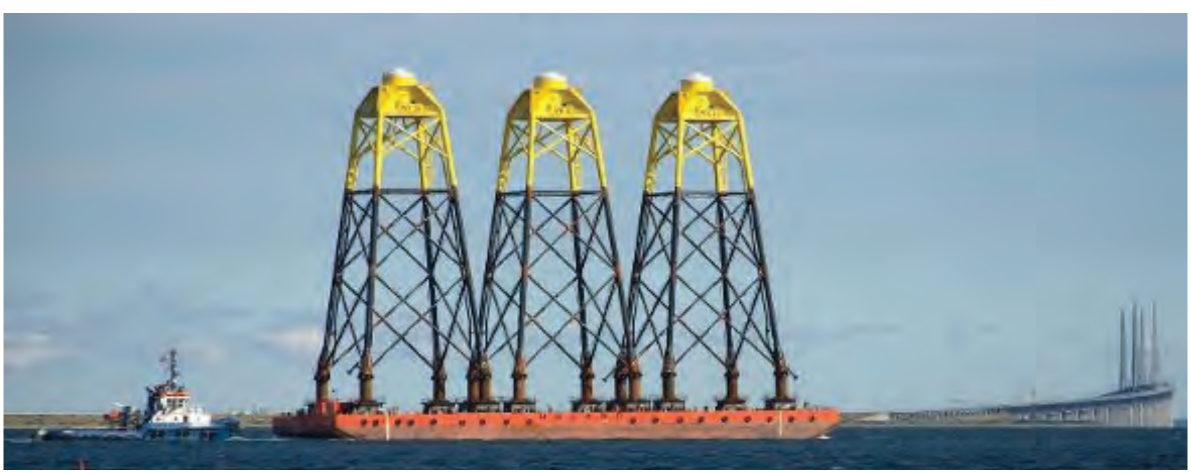
FIGURE 13.6: MONOPILE YARD AT THE PORT OF ROTTERDAM.

Source: SIF

Jackets

The most common option for a non-monopile steel foundation is the three- or four-legged steel jacket, a cross-braced and welded structure using steel tubes, and where each leg is fixed to the bottom using steel pin piles typically 2-3m in diameter. This type of foundation has been extensively utilized in the offshore oil AND gas industry and is often used to support offshore electrical infrastructure. It is commonly used where water depths exceed the limits of applicability for monopiles or where challenging soil conditions exist. Jackets have been applied on numerous European offshore wind projects, including Thornton Bank, Wikinger, Nordsee Ost, Baltic 2, and East Anglia 1, and are planned on further sites like Scottish Neart Na Gaoithe as well as on many Asian projects, including in Taiwan and China.

FIGURE 13.7: JACKETS BEING TOWED TO SITE.



Source: COWI

One of the established suppliers of jackets is UK-based BiFab, which delivered jackets for the Beatrice and Alpha Ventus demonstration projects and the Ormonde commercial project. Other leading players are OWEC Tower, German supplier EEW Danish Bladt, Spanish Navantia, and Belgium companies SIF & Smulders. The market could be attractive for Sri Lankan shipyards. Companies with shipbuilding or offshore oil platform experience may have an opportunity to participate in this emerging market for offshore WTG jackets, and similarly towers. However, they need to consider that while the production of jackets for oil and gas focuses on few but expensive units, the supply for offshore wind concentrates on large production volume at low cost. Therefore, their manufacturing facilities will require a high level of standardization and process optimization.

As with monopiles, it is not likely for a Sri Lankan supplier to enter the jacket fabrication supply market. From an economic point of view, the significant investment risk to enter the offshore wind market makes more sense for Indian manufacturers, who can leverage oil and gas or onshore wind expertise, and gradually ramp-up their capacity to supply the Sri Lankan market. Given the limited size of the Sri Lankan power demand, jacket foundations are unlikely to be in high demand for offshore wind projects in Sri Lanka, even in a high-growth scenario.

13.4.2 Electrical Infrastructure

Another major category in the BoP is the supply of the electrical infrastructure needed to discharge the electrical power from the offshore WTGs to the grid onshore. The first piece of electrical infrastructure is the system of several strings of medium voltage (MV) subsea cables, or inter-array cabling (IAC), which connects the WTGs and subsequently feeds into a local offshore substation. The second piece, the offshore substation, then steps up the voltage for transfer to the shore using HV export cables. Export cables then transfer power from the substation to a substation onshore.

The electrical layout highly depends on the distance to the shore and the size of the wind farm. At distances beyond 80-100km from shore or on power islands where several wind farms feed into a central hub, a high voltage direct current (HVDC) approach is also an option. This poses the advantage of reducing electrical losses on the cabling, but the investment for such systems is significant and a long lead time of five to seven years is likely. To date, only a handful of sites in Germany have applied HVDC setups, and for Sri Lanka, the most likely scenario for the short term are sites within reach for HVAC cables.

Export and Inter-array Cabling

The inter-array cabling connects the WTGs to an offshore substation but can also be applied to connect AC collector substations to a direct current (DC) grid connection. The vast majority of IAC are medium voltage alternate current connections (MVAC) rated at 33kV and made from cross-linked polyethylene (XLPE). The recent developments in WTG size have also led to potential designs using 66kV cabling as a basis for inter-array cabling, which has the advantage of reducing electrical losses. This progress would also allow keeping the relative number of WTGs currently allocated to a single string (between 6-8 per string), despite increasing power per WTG. While the array cable supply has historically been separated from the installation contract, this trend is beginning to change as developers strive towards a combined contract to minimize interface risks. For such integrated cases, it is most likely that the main contractor will remain the cable supplier.

The interconnection of the offshore station to the land-based grid is performed by means of high voltage export cables. These are considerably heavier and longer than the inter-array cables. These will most likely be alternating current (AC), which has been the most common setup to date. A high voltage alternating current setup (HVAC) could reach voltages of 320kV.

Sri Lanka is home to ACL Cables who should be able to develop production capacity to help meet some supply demands for Sri Lankan projects, and who are active in the international cable market.

Offshore Substation Supply

The offshore substation (OSS) collects the power generated from the WTGs and converts it to a higher voltage level to export it over subsea cables to a land-based transformer, which subsequently injects it into the transmission grid. The substation comprises of transformers, switchgear, controls, and fire protection systems and generally all relevant switching and protection systems necessary to respond to faults. Any other necessary power electronics and auxiliary low voltage systems are installed at the OSS as well.

The overall OSS foundation supports the electrical substation itself and all components for access and temporary accommodation facilities (together called topside), covering an area of around 30m x 30m and can reach several stories in size (see Figure 13.8). The total weight of the OSS topside can vary between 1,000 and 2,000 tonnes or more and, similarly to WTG foundations, is usually installed on jacket foundations and in single cases on monopiles or concrete gravity foundations.

FIGURE 13.8: OFFSHORE SUBSTATION AT BORSELLE BETA WIND FARM.

Source: HSM Offshore Energy

The OSS is a complex system, hosting a vast amount of equipment and numerous interfaces, but supply can roughly be divided into the three following categories:

- Providers of the support structures (jackets, monopiles, or gravity foundations),
- Supply of topsides, and
- Supply of electrical equipment.

The support structures can be provided by the same companies providing the foundations for the WTGs. Topsides are commonly produced by large yards like Bladt, Bilfinger, Hereema [90], Harland & Wolf [91], or Semco Maritime [92]. Sri Lanka does not specialize in the fabrication of heavy structures for marine applications, however, local firms such as Colombo Dockyard may be able to fabricate smaller components (e.g., 'secondary steel') or potentially be skilled up to assemble components.

Only a limited number of crucial players supply the electrical equipment for the offshore wind market. The key players holding most of the global market share are ABB, Siemens, Alstom, and CG Power. A single offshore substation can typically connect up to 1GW of wind power, so Sri Lanka is unlikely to require sufficient numbers needed to attract meaningful local supply chain investments.

13.4.3 Onshore Infrastructure and Substations

Once the voltage is stepped up by the OSS and transported to land utilizing export cables, the power is received at coastal onshore substations, which clean the power and convert it to be integrated into the onshore transmission grid.

There is almost no difference between onshore substations for wind farms and any other land-based power facilities, so domestic players and manufacturers such as DIMO [93], who is a partner of Siemens and specializes in engineering and project management for power transmission, power distribution, renewable power plants, and industrial power solutions, could supply this wind farm component.

13.5 INSTALLATION AND COMMISSIONING VESSELS

The installation of an offshore wind farm requires a wide variety of vessels, each with a specific design and purpose, and roughly split into the following vessel types:

- Heavy-lift vessels
- Derrick barges
- Transportation barges
- Jack-up barges without propulsion
- Self-propelled jack-up vessels
- Trenching vessels

- Cable laying barges (anchor driven)
- Cable laying vessels
- Rock dumping vessels (if offshore cable crossings occur)
- Guard vessel (during installation before hot commissioning)

These vessels serve to install the WTG foundations, the WTGs, the IAC and export cabling, and the offshore substation. After completing construction and commissioning, other vessels are involved, specifically related to O&M.

The ports involved in the construction need to comply with specific requirements to accommodate them according to the type of vessel. Typically, installation vessels are deployed worldwide, as the market size for offshore wind is limited within a given country and the upfront vessel building costs are too significant.

13.5.1 Foundation Installation Vessels

The foundation installation vessels first transport the foundations to the site and then execute the specific installation process depending on the foundation type, e.g., piling for monopiles. These tasks are usually performed by either floating heavy lift vessels and sheerleg crane vessels (in combination with an additional component feeding vessel) or by jack-up vessels, mainly used for WTG installation.

A variety of vessels have performed monopile installation, e.g., heavy lift vessels like Seaways' "Stanislav Yudin," crane vessels like Van Oord's "Svanen," or jack-up vessels like "Aeolus." The Sri Lankan industry would need to make major investments to bring foundation installation vessels to the Sri Lankan market. However, Sri Lankan shipyards, which already support the production of O&M vessels for western developers [94], could potentially construct larger vessels for the installation of foundations. But then again, such an investment would rely on a significant domestic pipeline of projects to realize shipbuilding for domestic use. While this pipeline is unlikely, a larger, regional pipeline offshore would see Sri Lankan vessels used in Indian projects and present many opportunities for growth.

The offshore wind industry requires jack-up vessels with crane capacities of at least 1,000 tonnes and large decks to accommodate a significant number of jackets (ideally five) per trip. The evolution to larger WTG sizes in Europe has led to a surplus of medium-sized jack-up vessels in the market that would be useful for supporting smaller WTG installations in Sri Lankan waters.

13.5.2 WTG Installation Vessels

WTG installation vessels also cover transportation to the site and installation of towers and WTGs. Because of the precision and stability needed to install the nacelle and blades, all commercial projects have solely applied jack-up vessels as a basis for WTG installation. The early years of the European industry were still able to rely on the application of general-purpose jack-up barges from the oil and gas sector, and at that time, these vessels were scarce in the market. However, because of sites with increasing water depths beyond 25m, in the last ten years, many of the leading suppliers like the UK-based MPI Offshore and Seajacks or Norway's Fred. Olsen Windcarrier started investing in jack-up vessels designed to the specific needs of the offshore wind industry.

FIGURE 13.9: WTG INSTALLATION VESSEL BOLD TERN.

Source: Fred. Olsen Windcarrier

Further examples of established players able to provide these vessels include Belgian Jan de Nul and DEME (who acquired Danish A2Sea), German SAL Heavy Lift, Danish Swire Blue Ocean, and Dutch Van Oord. Many of these actors are currently also ordering new cranes in order to cope with the increasing lifting heights and weights of the next generation WTGs. Accordingly, these purpose-built vessels are now widely available in the market, especially those able to operate with smaller WTGs. Given that these European suppliers have ordered their vessels in Asia in the past (primarily in China and Korea) and that their state-of-the-art fleet can operate globally, the chance for domestic suppliers to enter the WTG installation vessel market is very small. However, as the market grows worldwide, more opportunities may materialise.

13.5.3 Cable Installation Vessels

There are two different methods when using installation vessels for offshore cables. The first method performs a simultaneous lay and burial process with the aid of a plough, while the second method splits the tasks performing the surface lay first, and subsequently applies the burial using a jetting tool controlled by a remotely operated vehicle (ROV). The site conditions determine the approach for a particular site. This same process is performed for the IAC and the export cabling and requires two different kinds of vessels for each task. Export cables are preferably installed in one single length and need bigger ships with a larger cable carousel. Vessels for IAC are smaller than for export cables, but due to the high number of cable pulls and terminations at each foundation, the IAC installation is considered the more difficult task.

While in the past, the technically challenging process of cable installation has led to significant problems and was long a weak point of the industry, the sector has matured, and specialized companies with purpose-built vessels have developed in the market. One of the leading suppliers is Subsea 7, which acquired cable installer SIEM Offshore in 2018. Large cable manufacturers like Prysmian or Nexans and also major EPC contractors like Van Oord have also invested in dedicated vessels for their portfolio. Still, the task requires experienced staff and well-trained vessel crews and remains technically challenging. Even though cable installation providers act globally, local investors will remain hesitant to build domestic purpose-built vessels without strong policy support and commitment to a large pipeline from the government. Even with this support, the Indian market will continue to drive the demand for purpose-built vessels.

FIGURE 13.10: CABLE INSTALLATION VESSEL.

Source: Van Oord

13.5.4 Offshore substation installation vessels

The installation of the offshore substation topsides requires major heavy lift vessels, but the task is very similar to installing smaller oil rigs. As the amount of required substation installations is relatively small this will probably keep the market limited for vessels specifically dedicated to these types of activities.

13.6 OPERATION AND MAINTENANCE

As mentioned previously, O&M activities make up approximately 30 percent of the lifetime costs of an offshore wind farm and will to a wide extent be locally-sourced. Hence, O&M activities represent one main area in which the Sri Lankan supply chain will attract significant investment.

13.6.1 Wind Farm Operation

The daily operation of the wind farm will require a wind farm control center for monitoring the production and performance of offshore WTGs, which, depending on its capabilities, a developer or owner may choose to build and operate or subcontract the task to an asset management company. The operations center will work closely with storage facilities, vessel operators, and the maintenance organization. Wind farm operation is a balancing act between managing the electricity production whilst considering the logistics of servicing offshore structures and machinery. Because of this, the operation typically requires a dedicated CTV and a dedicated maintenance team that may service one or more wind farms. The work could consist of coordinating simple, annual, or scheduled maintenance and inspection tasks, monitoring the service provider, and handling warranty claims.

13.6.2 WTG Maintenance and Service

Typically, WTGs are provided with a warranty period, where the WTG supplier is responsible for maintenance. The maintenance organization is responsible for spare parts inventory, ensuring the availability of trained technicians and adequate vessel capability to service the WTGs. Balancing these constraints is a challenging task. The day-to-day maintenance of WTGs and replacement of minor parts may be rather easily accomplished; however, partial or complete replacement of major components such as gearboxes, bearings, blades, and electrical equipment may require the sourcing of items that have extended lead times. Generally, major repairs also require special vessels to install, which are subject to market availability and pricing.

Suitably-qualified and experienced personnel are crucial to undertaking effective O&M. Technicians typically travel out to the site every day by boat (see Figure 13.11), transfer across to the WTG (see Figure 13.12), climb the WTG, undertake the maintenance work, and then repeat, as appropriate before return to shore.

FIGURE 13.11: HIGH SPEED SERVICE VESSEL.

Source: COWI

It is quite physical work in a hostile environment and specific certificates and accreditations are required to perform the job safely offshore and at heights. Further, WTG manufacturers may use specific equipment that differ from others, and technicians may require multiple certifications to work on different WTG types. Many training providers have opened up to meet the demand and now include courses provided by manufacturers (such as Siemens), higher education courses, and commercial training providers. Roughly, the sector needs between 0.5 and 1.5 full-time equivalent jobs per operational WTG.

FIGURE 13.12: OFFSHORE WTG TECHNICIAN ACCESSING A WTG.

Source: Ørsted

WTGs typically come with a five-year warranty and an O&M agreement from the manufacturer. During this period, the manufacturer will typically employ the majority of technicians on site. After the warranty period, the owner/operator can opt to extend the O&M agreement or take over responsibility for the plant and directly employ the technicians. Some more 'hands-on' owners take responsibility earlier and have jointly-employed technicians working on the wind farm during the warranty period.

13.6.3 Balance of Plant Maintenance

The maintenance organization is also responsible for maintaining the foundations and electrical infrastructure, performing periodic inspections on substations on- and offshore, and carrying out seabed surveys to ensure the subsea cables remain buried. These works may be separate from the WTG O&M and can quickly be addressed by specialist companies in the local market. These activities can require specialized vessels and equipment, such as Offshore Service Vessels (OSVs) specially equipped for the tasks, and technicians with special training in certain areas, such as ROVs, diving, welding, and other tasks.

13.7 DECOMMISSIONING

As offshore wind is a relatively young industry, very few installed offshore wind farms have been decommissioned. However, decommissioning should be addressed early on in a project, with plans and financial guarantees sometimes required as part of the initial permitting process. Typical services that are required include technical engineering, project management, and planning and offshore works coordination. It is not unusual to create differing decommissioning concepts utilizing different equipment or vessels.

While Sri Lanka is a long way from decommissioning offshore wind farms, many local companies are likely to be engaged at the end of an offshore wind farm's useful life. Local ports are likely to play a central role in decommissioning activities as they are well poised to help coordinate, collect, store, and scrap equipment removed offshore. Furthermore, local heavy equipment companies may be needed to produce special, custom-designed equipment. Local engineering and offshore survey support will likely be required to aid in planning and preparation. Specialist and skilled welders, laborers, divers, and other equipment operators are likely to be needed, along with transportation barges and other vessels for scrap removal and recycling.

13.8 SUPPLY CHAIN ASSESSMENT

There are relatively few benefits for projects to source locally for many of the equipment/materials necessary to build and operate an offshore wind farm because they either carry relatively large investments with significant risk, or there is a well-established international (European, Indian) capacity to meet the demand which would be difficult for Sri Lankan companies to naturally compete with. The overall size of the Sri Lankan electricity market seriously limits options to develop the local supply chain, and local investments would need to be based not only on the needs of the Sri Lankan market, but also on serving the Indian market.

The rankings, based on metrics keeping alignment with similar roadmaps from other countries in the World Bank Group's roadmap series, are explained in Table 13.2. The assessment was made in consultation with local consultants and is divided into the following areas:

- Track Record and Capacity in Offshore Wind
- Capability in Parallel Sectors
- Benefits of Local Supply
- Investment Risk
- Size of the Opportunity

The rankings for Sri Lanka are given in Table 3.7.

TABLE 13.2: SCORING METRIC USED TO EVALUATE THE SUPPLY CHAIN IN SRI LANKA.

Track Record and Capacity in Offshore Wind	1	No experience
	2	Experience in supplying wind farm ≤ 100MW
	3	One company with experience of supplying wind farm > 100MW
	4	Two or more companies with experience of supplying wind farm > 100MW
Capability in Parallel Sectors	1	No relevant parallel sectors
	2	Relevant sectors with relevant workforce only
	3	Companies in parallel sectors that can enter market with high barriers to investment
	4	Companies in parallel sectors that can enter market with low barriers to investment
Benefits of Local Supply	1	No benefits in supplying projects locally
	2	Some benefits in supplying projects locally, but no significant impact on cost or risk
	3	Work for projects can be undertaken from outside country, but only with significant increased cost and risk
	4	Work for projects must be undertaken locally
Investment Risk	1	Investment that needs market certainty from offshore wind for five or more years
	2	Investment that needs market certainty from offshore wind for two to five years
	3	Low investment ≤ US$50 million that can also meet demand from other small sectors
	4	Low investment ≤ US$50 million that can also meet demand from other major sectors with market confidence
Size of the Opportunity for Sri Lanka	1	< 2% of lifetime expenditure
	2	2% ≤ 3.5%
	3	3.5%–5.0%
	4	> 5% of lifetime expenditure

The current state of the supply chain is reflected in Table 13.3. The scoring reflects that there is overall a number of areas where Sri Lanka has capabilities in parallel sectors, such as onshore wind and heavy construction; howeve, it lacks offshore experience in the same areas. In general, offshore wind projects would benefit most from Sri Lankan expertise in permitting and project development, along with operation and maintenance activities for the offshore wind farms. There are relatively few benefits to projects to source locally for many of the other items because they carry significant investment risk or there is a very established international capacity to meet the demand which would be difficult to compete with.

TABLE 13.3: EVALUATION OF SRI LANKAN SUPPLY CHAIN READINESS.

Category	Local Notable Companies	Country Track Record and Capacity in OSW	Sri Lanka Capability in Parallel Sectors	Benefits of Sri Lanka Supply	Investment Risk in Sri Lanka	Size of the Opportunity
Developing and permitting	WindForce, LTL Holdings — Ceylex Renewables	1	3	4	2	2
Nacelle, hub, and assembly	-	1	1	2	2	4
Blades	-	1	1	2	2	4
Tower	-	1	1	2	2	4
Foundation supply	Colombo Dockyard, Access Engineering	1	2	2	2	4
Array and export cable supply	-	1	1	2	2	4
Offshore substation supply	DIMO	1	2	2	2	3
Onshore infrastructure supply	Access Engineering, DIMO	1	4	3	3	1
WTG and foundation installation	-	1	1	1	4	2
Array and export cables installation	ACL Cables, DIMO	1	2	2	3	4
Wind farm operation	WindForce, LTL Holdings	1	3	4	4	4
WTG maintenance and service	WindForce, LTL Holdings	1	3	4	4	4
Balance of Plant (BoP) and various maintenance	Access Engineering, DIMO	1	3	4	4	4
Decommissioning	Access Engineering	1	2	4	4	2

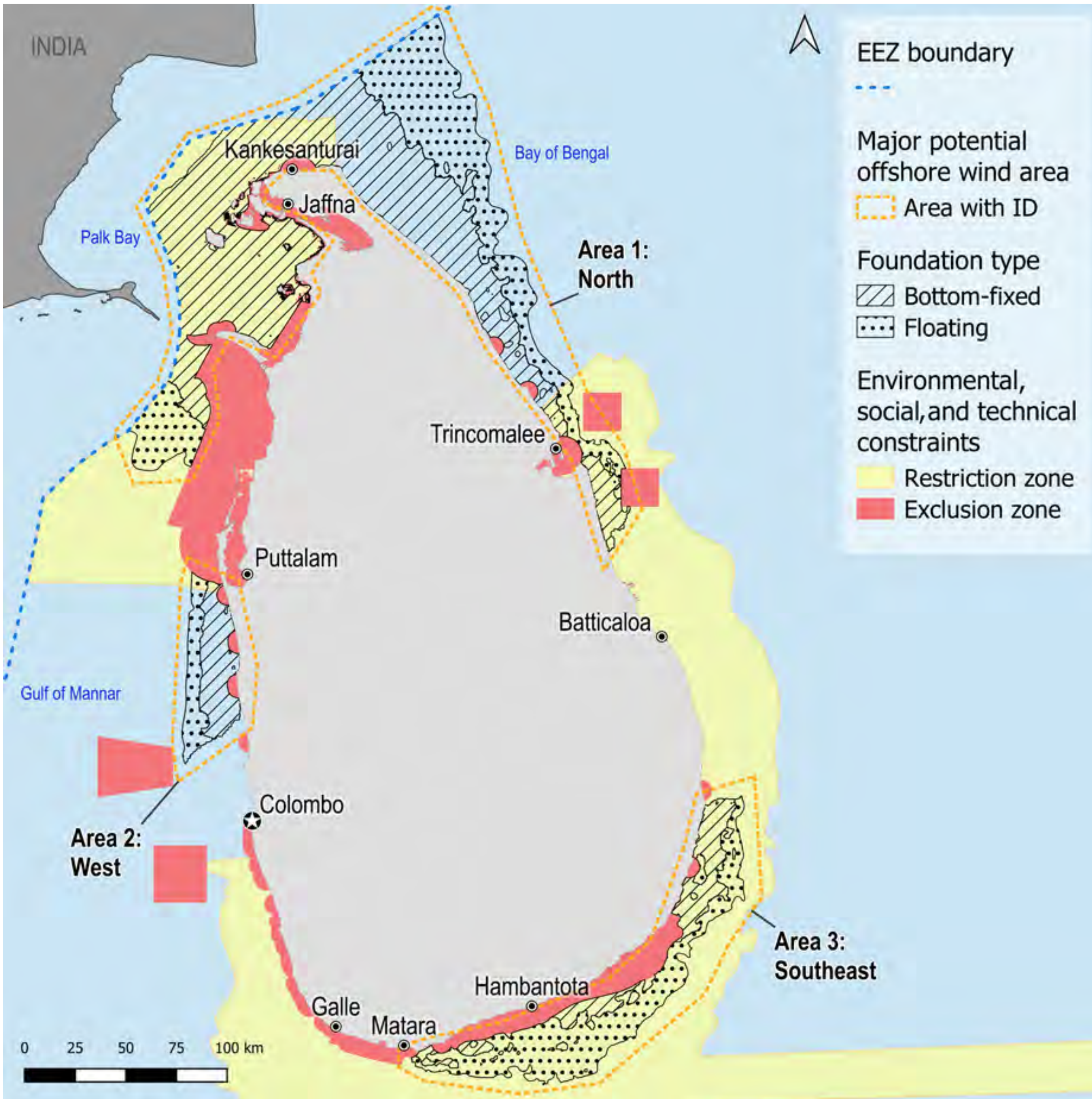
14 PATHFINDER PROJECT

Most new offshore wind markets start off with a pathfinder project to showcase the possibilities and opportunities to the developers in the market. A pathfinder project may also point out shortcomings or challenges within the regulatory framework or preparatory work for making offshore wind a success. Consequently, a pathfinder project in Sri Lanka will kick off the following larger development of offshore wind including supply chain and port development.

Following the screening for the roadmap and the resulting locational potential, we have looked into possible sites for a 500MW pathfinder project. The project needs to be of a sufficient size to create a good enough business case for developers. Seeing that SEA target 1GW offshore wind, a 500MW windfarm should be realistic.

A bottom-fixed offshore wind farm is preferred to a floating offshore wind farm since the technology is well-established, implying a lower cost as well as lower risk. The locational potential for both bottom-fixed and floating solutions has been mapped to three areas as seen in Figure 14.1 — see section 7 and section 3.1 for further information on the underlying spatial analysis. These three areas represent locational potential but with some restriction zones. The restriction zones indicate that further analyses are required on environmental and social matters, and that additional mitigation costs must be anticipated within these zones.

FIGURE 14.1: LOCATIONAL POTENTIAL FOR FIXED BOTTOM (HATCHED) AND FLOATING (DOTTED) OFFSHORE WIND IN SRI LANKA. RED MARKINGS INDICATE RESTRICTION ZONES FOR TECHNICAL, ENVIRONMENTAL, AND SOCIAL CONSTRAINTS.



Analysing the three areas in more detail especially regarding wind resource and transmission system provides considerations as outlined in the following section.

14.1 LOCATION OPTIONS

The options for the locations of a pathfinder project have been selected based on the following five considerations:

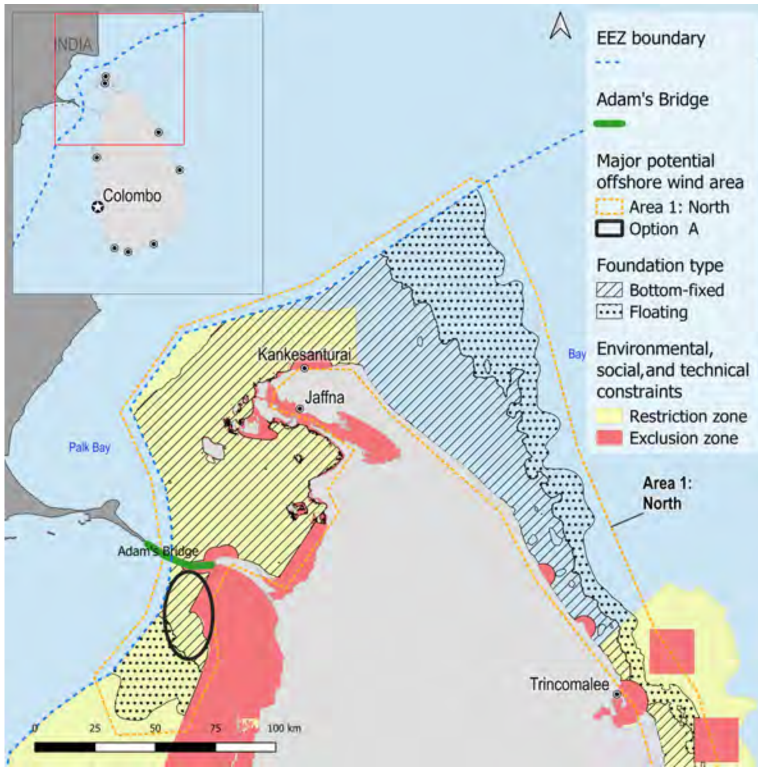
- Water depth allowing for bottom-fixed foundations
- High wind speed
- Environmental and social non-exclusion zone
- Good grid connection possibility
- Accessible from a suitable port

However, it shall be noted that for all location options there will be restriction zones which require a more detailed analysis before the location of a pathfinder project can be decided upon.

14.1.1 Option A — Mannar

In Area 1 (north) located around the northern tip of the country, the wind resource is good and water depths are to a large extent below 50m allowing for fixed bottom solutions. However, there is a "natural" restriction cutting off a large part of the area when considering a pathfinder project. Between the tip of Mannar Island in Sri Lanka and Danushkodi in India, there is a chain of natural limestone shoals believed to formerly have physically connected Sri Lanka and India. This formation is known as Adam's Bridge. Consequently, water depths in this area are very shallow, making it impossible for larger vessels to pass. This fact combined with no immediately suitable large ports on the eastern side of Sri Lanka de facto cuts the main part of Area 1 off as suitable for development of a pathfinder project.

FIGURE 14.2: AREA 1 (NORTH) AND OPTION A "GULF OF MANNAR" (BLACK OVAL).



The average wind speed in the area just south of Adam's Bridge is 8-9m/s which yields a fair wind resource.

Information on the transmission system from CEB shows that a transmission line of 220kV runs from Mannar island down towards the center of the island connecting it to the Colombo load center (see Figure 11.1). This is a very recently-built transmission line mainly for the connection of the 100MW onshore Mannar Wind Farm.

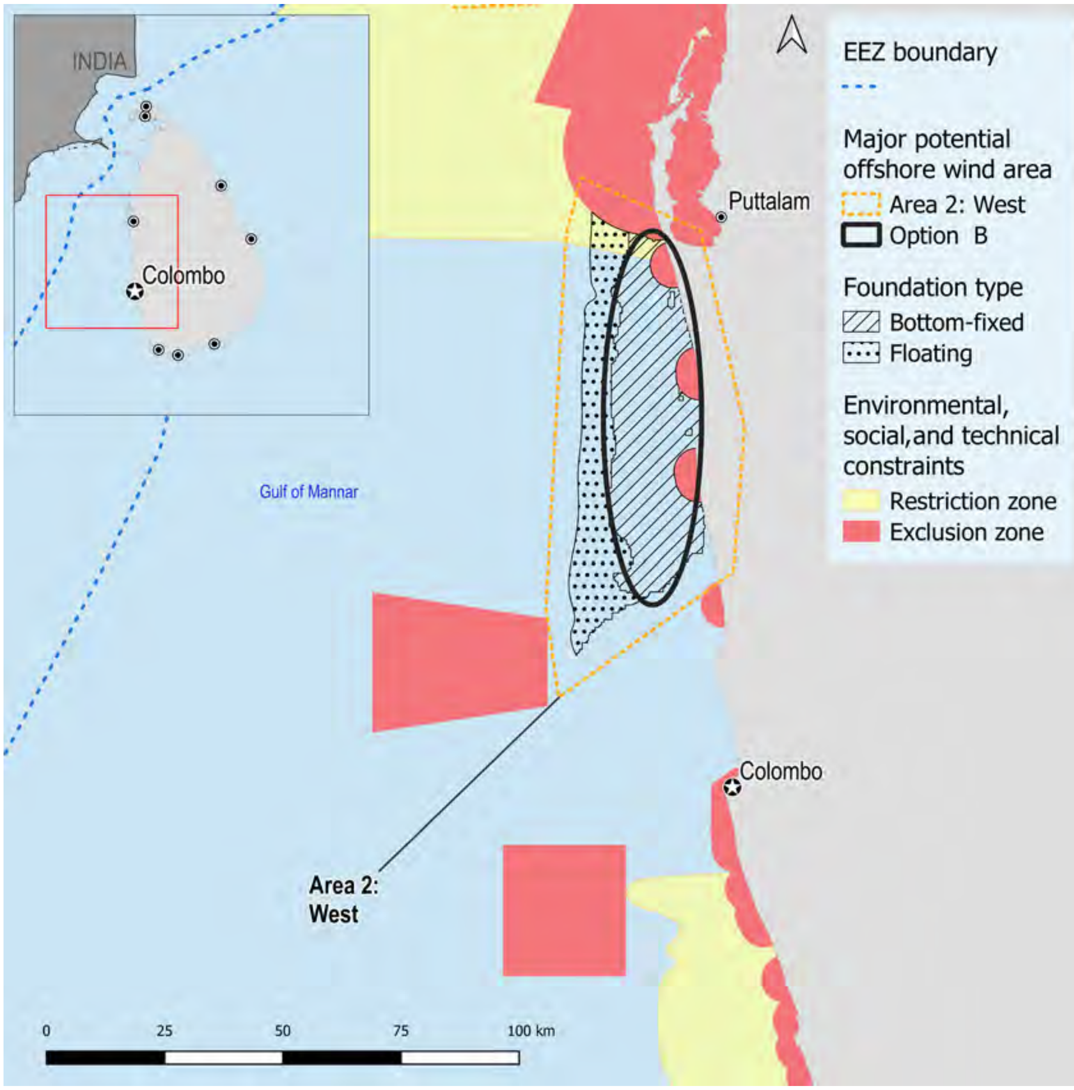
Considering the wind resource, the transmission system, and the availability of the port of Colombo, the Gulf of Mannar just south of Adam's Bridge shows good potential for a pathfinder project. Further, the area is sufficiently large to accommodate possible extension(s) to a pathfinder project which could be beneficial for a faster build-out of offshore wind. However, it shall be noted that the area contains environmental and social restriction zones which must be further investigated before launching a pathfinder project.

However, all of the Option A area is within a restriction zone which contains numerous, high-risk environmental and social sensitivities. The Option A area borders an in-shore area which is designated as a Marine Reserve (important for seagrass and dugong), so the export cable from a project to the shore would need to cross through this reserve. Furthermore, all of the Option A area is protected as both an EBSA and IMMA. Adam's Bridge is also culturally significant and any development in its vicinity is likely to have some perceived impact on cultural and religious heritage. Before this area can be considered for a pathfinder project, additional work is required to assess these sensitivities and better understand the potential impact offshore wind development could have.

14.1.2 Option B — Puttalam

Area 2 (west) has two advantages: 1) fewer environmental and social restrictions, and 2) location close to Sri Lanka's major electricity demand center and to the port of Colombo. However, the wind resource in this area is slightly lower than Option A, with average wind speeds in the range of 7.5-8.5m/s.

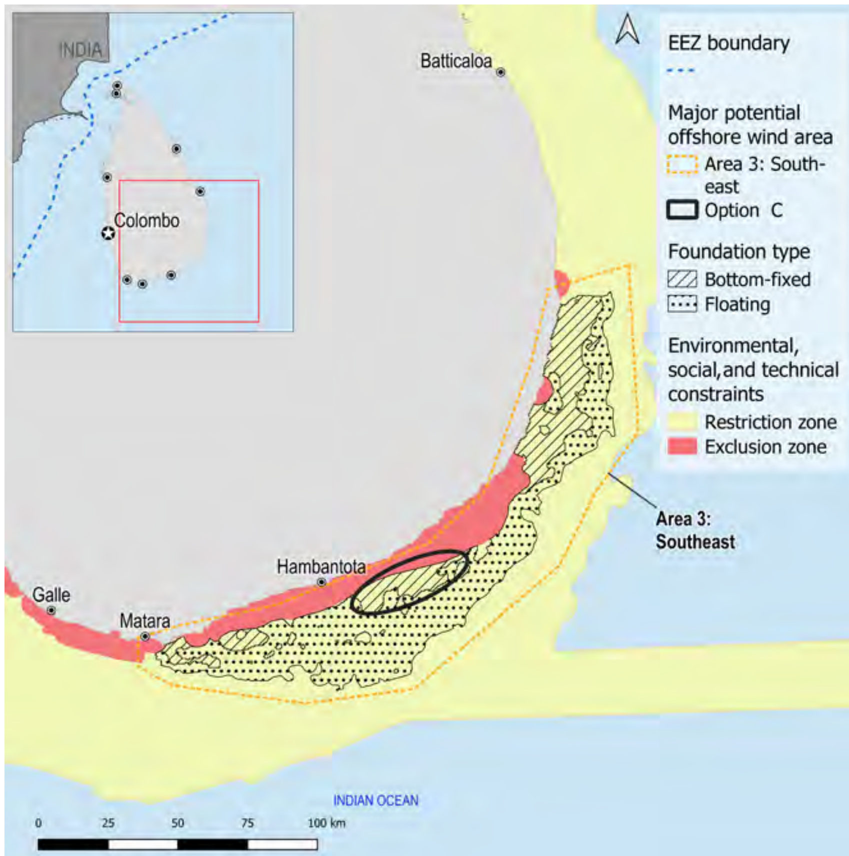
FIGURE 14.3: AREA 2 AND OPTION B "PUTTALAM".



14.1.3 Option C — Hambantota

The third and last option is Option C "Hambantota". This option is within Area 3 (southeast) which shows fair, average wind speeds of 8-9m/s.

FIGURE 14.4: AREA 3 AND OPTION C "HAMBANTOTA".



The most recent information on the transmission system received from CEB indicates that a transmission line of 220kV connecting Hambantota to the national grid will be constructed within the coming two to three years. This could then facilitate export of power generated from offshore wind in Area 3. Further, a location close to Hambantota provides for possible suitable port facilities.

However, all of Area 3 is within a restriction zone which contains numerous, high-risk, environmental, and social sensitivities. The area close to the coast is designated as a Marine Reserve, so the export cable from a project to the shore would need to cross through this reserve. Many of the beaches along this coast are important for turtle nesting, and this could limit options for cable landfall. Furthermore, the majority of Area 3 is protected as both an EBSA and IMMA. Before this area can be considered for a pathfinder project, additional work is required to assess these sensitivities and better understand the potential impact offshore wind development could have.

Considering the wind resource and the transmission system, Option C "Hambantota" also shows good potential for a pathfinder project. However, the area suitable for fixed bottom foundations is smaller and more diversified than in the Gulf of Mannar. Thus, the potential for extensions of a pathfinder project is limited and more complex.

14.1.4 Recommendation on Location of Pathfinder Project

From a "rough screening" point of view considering water depth, wind resource, and environmental and social constraints, Option A and Option C are quite similar. The similarity also goes for considerations on port facilities and possible grid connection. Option B has the advantage of fewer environmental, social, and technical constraints but has lower wind speeds.

TABLE 14.1: OVERVIEW OF KEY CONSIDERATIONS FOR THE THREE OPTIONS FOR LOCATION OF A PATHFINDER PROJECT.

Option	Water Depth Less Than 50m	Wind Speed	Environmental and Social Restrictions	Grid Connection	Port
A Gulf of Mannar	Yes	8-9m/s	High risk (within EBSA & IMMA)	220kV line	Colombo / Tuticorin in India
B Puttalam	Yes	7.5-8.5m/s	Lower risk	220kV line	Colombo / Tuticorin in India
C Hambantota	Yes (limited)	8-9m/s	High risk (within EBSA & IMMA)	220kV line (to be constructed)	Hambantota

Options A and C both feature substantial environmental and social sensitivities. A protected marine area runs along the southeast coast, meaning that the electrical export system from any project in the Option C area would need to pass through this. Furthermore, the onshore grid in this region is weak (though there are plans to improve it) and, although metocean conditions have not been investigated in this roadmap, the southeast coast will be exposed to more severe wave conditions. Option C also has unknown bathymetry, but with indications of a steep seabed that deepens quickly. There may be some shallower water in this area, but it is likely that much of it will be deeper and only suited to floating wind turbines.

While Option B has a less energetic wind resource, it appears to have fewer environmental and social sensitivities. It is also close to the port of Colombo and to existing transmission grid.

Options A and B in the Gulf of Mannar are closest to India and could offer synergies with the planned offshore wind projects in Tamil Nadu. Cooperation with India in this region could be essential in bringing the benefits of large-scale development to Sri Lanka.

From the information available on these three areas, Option A (Mannar) and Option B (Puttalam) appear to be more favorable for Sri Lanka's first offshore wind project and it is recommended that the feasibility of both areas is investigated further.

As Option A, Mannar, has a higher wind resource, it is likely to have a lower LCOE than a project at the Option B, Puttalam location. For this reason, this analysis focuses on Mannar as a possible location of a pathfinder project. To achieve some economies of scale and provide a project scale that is attractive to investors, a 500MW pathfinder project has been assessed.

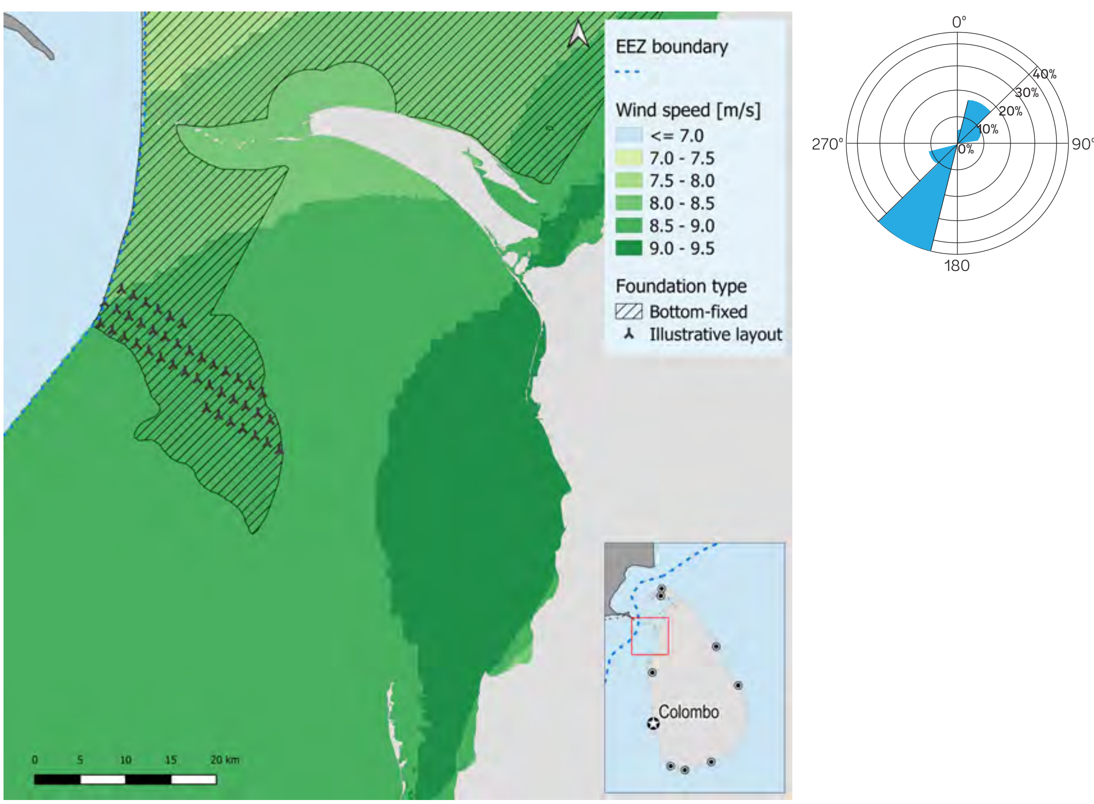
14.2 PATHFINDER PROJECT CONCEPT LAYOUT

The potential concept layout uses a Class I 12MW WTG with a rotor diameter of 220m and at a hub height (HH) of 150m. This WTG has been selected as it is readily available in the market and considered suitable for the wind speed of 8-9m/s. The selection of this WTG model, however, reflects no endorsement towards a specific model, and it will be up to the developer to evaluate which WTG is most suitable for the specific site. As such, a generic power curve has been selected for this WTG size based on experience and market trends. However, power curves for specific models will deviate depending on the Power, rotor size, swept area, and controller. This will have a small effect on the AEP, especially in areas of lower wind.

At this highly initial stage, a regular and symmetric layout consisting of straight rows has been considered with focus only on minimising the wake loss. This means that the row orientations are selected considering the wind direction distribution (wind rose). No yield optimization tools have been used, and a further optimization process will not only depend on the wind resource and wind direction but also on the WTG control strategy, further assessment of wake parameters, climatic conditions, etc.

Consequently, it must be noted that this concept layout is for illustrative purpose only and may in no way be construed as useable for design purposes.

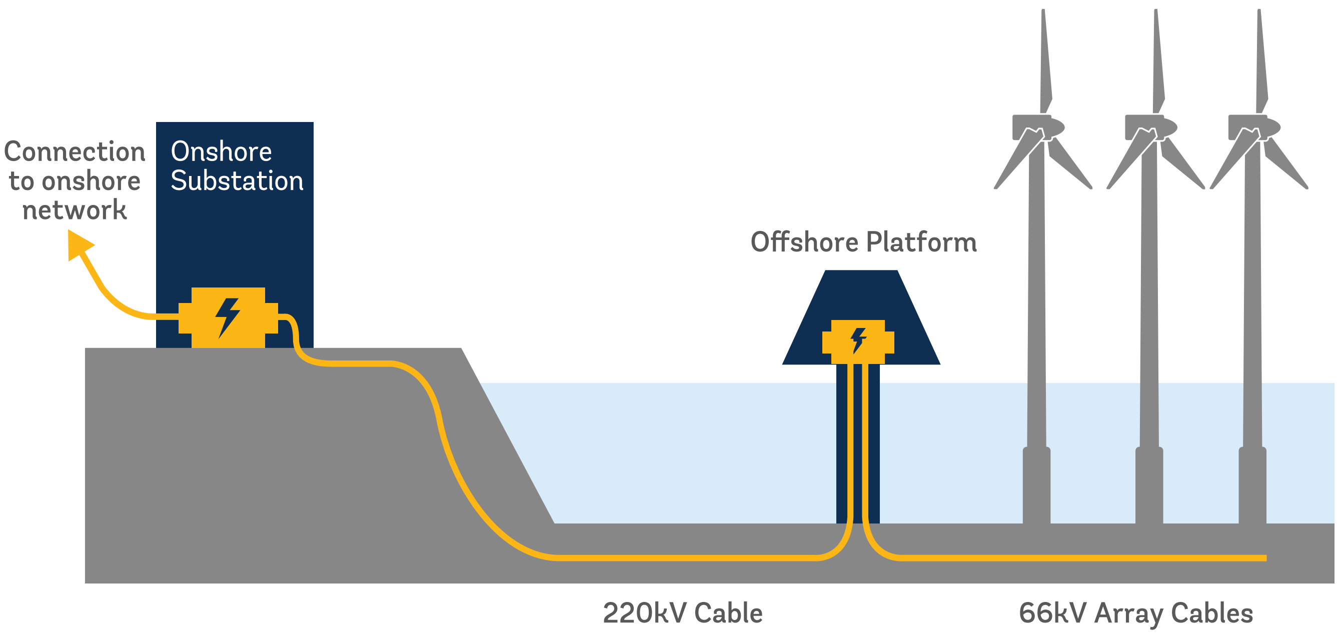
FIGURE 14.5: ILLUSTRATIVE LAYOUT OF A 500MW PATHFINDER PROJECT CONSISTING OF 42 X 12MW WTGS AT 150M HH, ALONG WITH A FIGURE SHOWING THE WIND ROSE FOR THE AREA.



With a conceptual layout of the WTG positions, it is also possible to illustrate what a possible electrical network and export system could look like. The electrical network and export system consists of the following main components:

- 66kV array cables connecting the WTGs in strings and to the offshore substation
- An offshore substation collecting the generated power from the WTG strings through the array cables, stepping up the power from 66kV to 220kV
- Two 220kV subsea export cables exporting the generated power from the OSS to shore.
- A transition joint bay at landfall connecting the subsea export cables to onshore export cables
- Two 220kV onshore export cables connecting to an onshore substation

FIGURE 14.6: ILLUSTRATION OF A HIGH-LEVEL ELECTRICAL CONCEPT FOR AN OWF.



14.3 AEP AND LCOE

A rough estimate of the AEP from a 500MW pathfinder project located in the Gulf of Mannar and south of Adam's Bridge using a 12MW WTG has been estimated as outlined in Table 14.2.

TABLE 14.2: AEP ESTIMATE FOR 500MW PATHFINDER PROJECT IN THE GULF OF MANNAR.

Wind speed	8.8m/s
Nos. of 12MW WTGs (150m hub height)	42
Annual gross energy production (P50)	2,535GWh
Wake loss (assuming 4.0%)	101.4GWh
Annual gross energy production (P50) (including wake losses)	2,433GWh
Gross capacity factor	55.1%
Other losses — electrical, outages, etc. (10% of P50)	243GWh
Net AEP	2,190GWh
LCOE[65]	75 US$/MWh

It must be noted that this estimate is highly uncertain as it is based on an un-optimized layout with losses only roughly estimated. Furthermore, it does not take into account any uncertainties, so this should be considered as a high-level, preliminary estimate which inherently will change once the optimization process and detailed analyses have been carried out.

Using the CAPEX and OPEX assumptions from the financial analyses in section 9.1 including a target WACC of six percent (which is heavily contingent on concessional finance and sufficient risk mitigation) and applying a net AEP of approximately 2,190GWh per year for the 500MW pathfinder project, yields an LCOE of around US$75 per MWh.

This is slightly lower than the estimated average LCOE stated in section 9.1 (Figure 9.2). The reason for this is mainly that the site selected for the pathfinder project has better wind resource than when averaging the wind resource throughout the locational potential of Sri Lanka. The costs per MW installed capacity are assumed to be in the same range as for larger sites. There are factors which could result in higher as well as lower costs, and this may be explored in a more detailed study.

14.4 NEXT STEPS

One of the immediate next steps is to undertake more analysis to inform the location of the pathfinder project. For this, a pre-feasibility study considering the various options for the location of a pathfinder project must be conducted focusing on a screening exercise providing LCOEs for the different possibilities, taking environmental and social constraints as well as grid reinforcement into consideration. This process should also include stakeholder consultation to better understand the constraints.

Section 4.3 describes the next steps in more detail and provides an indicative timeline for their implementation. Section 15 also provides further information on specific studies and surveys, as well as providing rough cost estimates.

65 Assumptions on CAPEX and OPEX are the same as described in Table 9.1 scaled to 500MW. The LCOE is based on an expected WACC of six percent that depends on sufficient risk reduction and the use of concessional finance.

15 PREPARATORY STUDIES

Preparatory studies comprise the further investigations required to mature an offshore wind power project for design and construction. Several studies are required including the following:

- Soil (seabed) conditions
- Metocean
- Wind resource
- ESIA
- Grid integration

15.1 SOIL CONDITIONS

Soil conditions cover the nature and characteristics of the seabed and the ground beneath. These conditions drive and determine the design of WTG foundations and offshore substation foundation, as well as cable design and routing.

Establishing soil conditions for design of an offshore wind farm comprise several surveys and investigations. The two major categories are geophysical and geotechnical studies.

15.1.1 Geophysical Investigations

Surface investigations which map the seabed (depth, bathymetry, structure, objects, and hazards e.g., Unexploded Ordnance (UXO)) often include a scan of the top layers of the seabed. The investigation is carried out by equipment hanging from the rear end of a vessel into the water column. The vessel then scans the seabed by moving in a grid (of e.g., 200m).

These investigations provide a significant amount of data and information and typically cost in the region of US$1-3 million for a typical 250-500MW project.

15.1.2 Geotechnical Investigations

Geotechnical investigations comprise drilling, bore samples, and cone penetrating testing (CPT). These investigations determine the strength parameters of soil at specific locations. Geotechnical investigations can be made from a specialized ship or a jack-up vessel, and consequently carry higher cost. However, such investigations are crucial for preparing the design of the offshore structures.

The cost of a full soil condition assessment including surveys is around US$10-15 million, depending upon many factors such as site size and vessel availability.

15.2 METOCEAN CONDITIONS

Metocean conditions refer to the combined wind, wave, and climate conditions found at a specific location. Metocean conditions are important for the WTG locations but also for the transmission system design.

The purpose of a metocean study is to provide information and data at a level of detail which will sufficiently enable developers to submit qualified financial bids for design and construction of an offshore wind farm. It is recommended that the metocean study is prepared in accordance with IEC 61400-3 "International Standard — wind turbines — Part 3: Design requirements for offshore wind turbines." A thorough and certified metocean study significantly reduces risk for developers.

A metocean study for an offshore wind farm in Sri Lanka should include the following data:

- Location (coordinates) and general site description
- Bathymetry and tidal data
- Wind data
- Wave data

Based on the site-specific data, hydrodynamic modelling, wave transformation, and hindcast simulations can be conducted for use towards the design of the offshore structures.

The full cost of a metocean desktop study is around US$75,000 for a typical 250-500MW project. The cost of the long-term measurements is detailed in the following section as part of the wind study by means of a floating LiDAR buoy.

15.3 WIND STUDY

In order to properly estimate the annual energy production (AEP) and the structural requirements to the WTGs, it is necessary to conduct a thorough wind study based on site specific measurements.

The Global Wind Atlas [9], although a highly advanced tool, relies on mesoscale data and not site-specific data. For Sri Lanka, it will be necessary to conduct specific measurements on site with a floating Light Detection and Ranging (LiDAR) system.

A site-specific wind study should include the following topics:

- Site boundaries (coordinates)
- LiDAR data (position, measuring period, calibration)
- Mesoscale data
- Validation of data
- Wind speed and distribution
- Seasonal, monthly, and daily variation

- Wind shear
- Long term variation and correlation
- WTG suitability and site-specific requirements
- Layout optimization
- AEP calculations (gross and net)
- Loss estimation (wake, power curve, electrical, availability, etc.)
- Uncertainty estimation (P50, P70, P90)

A floating LiDAR measurement campaign, spanning over a length of 12 months, typically carries a cost of at least US$1.0-1.5 million, but could be more, depending on the site conditions and equipment availability.

In some cases, particularly in emerging markets, it may be more cost effective to deploy a fixed structure offshore and install a regular LiDAR unit on it (this, for example, was done in Gujarat as part of the FOWPI project). This option should be considered alongside the floating LiDAR campaign.

A wind resource study (including processing the LiDAR data) for a typical 250-500MW offshore wind farm is approximately US$20,000 to US$40,000.

15.4 ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT

An environmental and social impact statement for an offshore wind farm is a very extensive document that must cover several different topics. The assessment falls into two main categories:

- Environmental impact
- Human related impact (including 'social' and 'technical' issues)

The IFC performance standard "Environmental, Health, and Safety Guidelines for Wind Energy" may be used as guidance for what should be covered in an ESIA. However, it is important that local rules and regulations are respected and incorporated in the analysis.

15.4.1 Environmental (biodiversity) Impact

Offshore wind farms have the potential for direct and indirect adverse impacts on both onshore and offshore biodiversity during construction, O&M, and decommissioning. Examples of impacts include bird collision-related fatalities; displacement of wildlife; habitat conversion/degradation; and noise to marine mammals. In offshore environments, benthic disturbance and new structures may also impact existing habitats and attract new habitat-forming species, such as shellfish, corals, and underwater vegetation. Adverse impacts can also result from associated infrastructure, particularly overhead transmission lines, substations, underwater cables, and vessel traffic.

Following a scoping and desktop study, appropriate site-specific baseline biodiversity information will be needed for the ESIA. Robust biodiversity baseline surveys are required to be completed in line with GIIP and should occur as early as possible, as they can require a minimum of two years of data collection, and should consider seasonality.

Surveys should consider the following:

- **Site-specific issues**: consideration of habitats, geographical location, topography, and vicinity of the wind farm to sites of high biodiversity value.
- **Species-specific issues**: surveys should be targeted to species of flora and fauna of high biodiversity value, those with a special international or national conservation status, endemic species, and species that are at elevated risk of impact from wind energy facilities. These impacts and potential mitigation options should be assessed on a species-by-species basis.
- **Season-specific issues**: surveys should take into consideration certain periods during the year when the project site may have a greater or different ecological function or value (e.g., migration, or breeding season). Surveys should usually be conducted for at least one year when at-risk wildlife is identified. Longer surveys may sometimes be necessary in areas with exceptional aggregations of at-risk migratory birds and where existing biodiversity data are limited.

15.4.2 Human-related Impact

Human-related impact covers several different topics of both public, commercial, and governmental interest. The main topics to be covered under this heading are:

- Fisheries and aquaculture
- Shipping
- Impact on recreation and tourism activities
- Visual impact
- Cultural heritage
- Military
- Aviation
- Telecommunication
- Oil and gas exploration
- Underground cables and pipelines
- Dredging

All these topics require site-specific information and data from relevant authorities and stakeholders. Consequently, it is beneficial to the process to engage with relevant stakeholders early on. It is recommended to initiate the ESIA process with a public hearing as an early consultation already during the scoping phase of the ESIA. With an early consultation, the public will be allowed to provide ideas and input feeding into the ESIA.

15.5 GRID INTEGRATION

The electrical grid integration studies shall involve both the offshore wind farm and the TSO.

It is important distinguishing between the:

- Reinforcement of the back-bone transmission systems; and
- Planning of the offshore wind farm grid interconnection.

The interface is the point of connection (PoC) where the TSO allocate HV connection line bays in one of his substations.

15.5.1 Reinforcement of the Back-bone Transmission Systems

The TSO shall plan, construct, and maintain a power grid with sufficient capacity and availability to secure the transmission between the generating units and the load demand centers. This is a non-stop process where the TSO issues an annually-updated master plan for the next one, five, ten, and 15 years for his concession area. Since the power grid is integrated across the country to secure stability, the TSO will also plan for eventual heavy interconnectors to neighboring countries (using subsea cables, or overhead lines either with an AC or HVDC approach). Upgrading of the backbone system will involve both new substations and overhead lines that will require a long planning horizon of 3-5 years[66]. Environmental issues and securing the rights of way for the line corridors are often key factors for such plants. Consequently, it is vital for the TSO to have an updated plan for new-builds and dismantling of the generation plants, as well as a good understanding of the power load demand.

With respect to integration of offshore wind to the grid, the projects will be considered like a thermal, hydro or other VRE generation plant[67]. The impact of the new generation plants might trigger new lines/SS that will be identified by TSO's electrical system studies "load-flow, transient/dynamic" that will reveal the need and timing for the construction/reinforcement.

Since the backbone power grid is of national importance, the TSO are often reluctant to share necessary details for external advisors, thus these studies for Sri Lanka are assumed to be implemented solely by the TSO.

However, if international investment banks are involved in the financing of such grid reinforcement initiatives it is assumed that an external international advisor/consultant will contribute with a high-level assessment and quality assurance on the planning process and eventually assist with drafting feasibility studies for the individual projects. Depending on the number of reinforcement projects a rough budget estimate for such studies could be in the range of US$600,000-2,400,000.

66 Environmental issues and secure of right of way often is a key factor/challenge.

67 The power balancing challenge will be addressed in the design of the dispatch centers.

15.5.2 Offshore Wind Grid Integration

The offshore wind developer will often be granted a certain lease area and then it will be their own duty to establish a sound power infrastructure system between the WTG and the PoC.

The development of the electrical infrastructure for an OWF aims at identifying the optimal topology and most cost-efficient technology available for the investor. The planning will take basis in the prevailing grid code requirement set out by the TSO where the conditions and requirements in respect to voltage quality and electrical interaction between the OWF and the grid at the connection point are detailed.

The OWF grid interconnection planning will involve the determination of the following:

- PoC location(s) and voltage level made available by the TSO
- Number of export cables to the PoC and selection of either AC or HVDC technology
- Number, location of offshore substations within the OWF
- Location of landfall and corridor for the onshore export cable

These determinations will be the results of sequential electrical studies (with detailed level of insight) and the technical/cost optimization of the power infrastructure where also the OPEX (energy loss assessment) shall be factored in.

The TSO often will identify a range and details of the electrical system studies requested to verify grid code compliance.

The electrical studies can be:

- **Initial load flow and short circuit studies**

  These will constitute the basis for determining the power system topology and give rating of the main components within the OWF and at the OnSS nearby the TSO PoC. High-level route plans and general arrangement of the OSS & OnSS will be established.

  These studies are typically implemented in the early developing process and form part of the developers bid process. Initial dialog with the TSO to identify suitable PoC(s) shall be made.

  Indicative budget: US$250,000-500,000.

- **Basic electrical studies (after concession is obtained)**

  A more detailed assessment of the request for components in the OnSS in respect to fulfilment of the grid code compliance will be required. Different WTG types and sizes might be considered. Final sizing of HV component/plants[68] targeting the voltage quality shall be implemented and will constitute the basis for the design and procurement of the BoP components. Initial assessment on harmonic filter in the OnSS will also be implemented. The basic studies will consider initial WTG sizes and a tentative OWF layout where the array cables interconnecting the WTG are incorporated.

  Indicative budget: US$350,000-700,000.

68 Reactive power and power factor control maintained by proper sizing/selection of shunt reactors, capacitor banks, static synchronous compensators, or similar.

- **Detailed electrical studies (after WTG contract award)**

  The final detailed studies will rely on the final selection of WTG size and location. The detailed electrical model of the WTG agreed will form basis for a final fine-tuning of the OnSS HV component ratings and also give basis to identify the size/rating of the harmonic filter banks[69].

  These studies will also involve transient and dynamic simulations that only can be implemented by use of very specialized software tools.

  Target is obtaining preliminary agreement with TSO prior to commencement of the manufacturing of main electrical components.

  Indicative budget: US$350,000-700,000.

- **As-built grid compliance studies (after construction)**

  During the test and commissioning of the OWF several measurements of the electrical plant characteristics and overall performance will be executed. Final electrical studies will complement the verification of the OWF grid code compliance and constitute the final acceptance from the TSO for OWF grid connection and operation.

  Indicative budget: US$250,000-500,000.

15.6 PORT AUTHORITY CONSULTATION (SHORT, MEDIUM, AND LONG TERM)

The Consultation or Study with Local authorities should focus on the development of port facilities in two major areas: Transport and Installation and Operations and Maintenance, as well as looking to the short- and medium-term solutions.

In general, it is recommended, given Sri Lanka's commitment to offshore wind, that a medium-term view of port development is adopted instead of a short-term view, in order that future projects will be similarly supported, reducing the CAPEX per project due to repetitive savings.

However, a short-term study may still be performed to show a clear relationship between medium-term planning and cost savings.

15.6.1 High-level Port Assessment

Specific temporary requirements for a large-scale installation campaign, including office space, supporting vessel berthing (CTVs, jackup barge, cable laying vessel, cable burial and trenching, etc.), crane installation, and onshore rigging. It should be noted that for such a large project, many tasks will be running concurrently and therefore it is essential to have sufficient berthing space to allow these tasks to be performed without bottlenecks on the processes.

- Assessment of candidate port(s) suitability for OWF construction ports including:
  - Size and depth of port sea access
  - Berth availability

69 These will be required by TSO to minimize/eliminate harmonic distortion injected into the power grid by the OWF.

- Laydown yard
- Land side access arrangements, etc.

- How long would it take to implement a temporary solution and decommission it (to give an idea of the total time the area will be not available for commercial use)?
- What will be the impact for the local community and environment of a temporary solution?
- What is the time scale of such a temporary solution to implement and how does it affect the critical path?

Indicative budget: US$50,000-100,000.

15.6.2 Detailed Port Study

In terms of determining a longer-term strategy, the following should be considered.

Development of a fixed berthing for at least two wind farm installation campaigns concurrently, but most likely not sharing resources. Development of the model for expanding the port to the necessary size, feasibility, cost, and critical path for project development.

At what point does it become feasible to invest in further port infrastructure? Is there a cut-off for one and two additional berths based on the expectations of future offshore wind investment in the area? The total viable available wind resource suggests that an investment in a "wind installation hub" would be a feasible option to open up the possibility of easier construction for up to 10GW of wind in the immediate area.

What would be required for a port expansion to service medium term, medium-to-large scale offshore wind installations?

- Expanded port entrance width to 200m minimum.
- Several dedicated berthings of >200m each, preferably each serviced by a dedicated craneage, office, consumables storage, and security.
- Expansion of port access by land, to allow for increased traffic and size.
- Improvement of port facilities (e.g., secure storage, office space, etc.).
- Expansion of sea-facing port facilities such as port entrance, depth, and protection.
- Consideration of construction of multiple windfarms simultaneously from a single port.
- Consideration of operations and maintenance activities and requirements.
- Site visits and consultation with local stakeholders.

Indicative budget: US$300,000-600,000.

16 STAKEHOLDERS

The key stakeholders that have been identified are listed in Table 16.1 under four main groups:

- **Government**: Government departments, regulators, and institutions at national and regional level.
- **International non-governmental organizations (NGOs)**: International NGOs with an interest in offshore wind in Sri Lanka.
- **National non-governmental organizations (NGOs)**: National NGOs with an interest in offshore wind in Sri Lanka.
- **Academia and civil society**: National and international academic institutions and civil society organizations with an interest in offshore wind in Sri Lanka.

TABLE 16.1: LIST OF KEY STAKEHOLDERS FOR OFFSHORE WIND DEVELOPMENT IN SRI LANKA.

Name	Website
Governmental	
Ministry of Power and Renewable Energy	http://powermin.gov.lk/
Sustainable Energy Authority	https://www.energy.gov.lk/
Ceylon Electricity Board	https://ceb.lk/
National NGOs	
Wind Force Ltd	https://windforce.lk/
LTL Holdings Ltd	https://ltl.lk/ltl-holdings/
Senok Wind Power Pvt	https://www.senoksl.com/
Lanka Transformers	https://ltl.lk/
Ceylex Renewables	https://www.ceylexrenewables.com/
Chamber of Commerce	https://www.chamber.lk/
International NGOs	
IFC	https://www.ifc.org/
Asian Development Bank	https://www.adb.org/
Japan International Cooperation Agency	https://www.jica.go.jp/
Academia	
University of Moratuwa	https://uom.lk/
Open University of Sri Lanka	https://ou.ac.lk/
University of Jafna	http://www.jfn.ac.lk/

The following organizations were invited to stakeholder consultations:

- **Government stakeholders**: Ministry of Power and Renewable Energy, Sustainable Energy Authority, Ceylon Electricity Board
- **Private sector stakeholders, including project developers**: Wind Force Ltd, LTL Holdings Ltd, Senok Wind Power Pvt. Ltd. Lanka Transformers, Celex Renewables, Chamber of Commerce (committee on renewable energy), Celex Renewables
- **Domestic Financial Institutions**: NDB Bank, DFCC Bank PLC, Commercial Bank of Ceylon PLC
- **International Financial Institutions**: IFC, Asian Development Bank, Japan International Cooperation Agency (JICA)

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ACRONYMS AND ABBREVIATIONS

GENERAL ACRONYMS AND ABBREVIATIONS:

ABEX	Abandonment expenditures
AC	Alternating current
AIS	Automatic Identification System
AEP	Annual energy production
BoP	Balance of plant
BST	Basic safety training
CAPEX	Capital expenditures
CCH	Cetaceans' critical habitats
CfD	Contract for difference
COD	Commercial operation date
CPT	Cone penetrating testing
CTV	Crew transfer vessel
DBFO	Design, build, finance, operate
DC	Direct current
DEVEX	Development expenditures
EBSA	Ecologically or Biologically Significant Marine Areas
EENS	Expected energy not served
EHS	Environmental, Health, and Safety
EIA	Environmental impact assessment
ESIA	Environmental and Social Impact Assessment
ENS	Energy not served
EPC	Engineering, procurement, and construction
EPCI	Engineering, procurement, construction, and installation
EUR	Euro
FiT	Feed in tariff
FTE	Full time equivalent
GDP	Gross domestic product
GVA	Gross value added

GW	Gigawatt
HH	Hub height
H&S	Health and safety
HV	High voltage
HVDC	High voltage direct current
IAC	Inter array cables
IBA	Important Bird and Biodiversity Areas
IEIA	Initial environmental impact assessment
IMMA	Important marine mammal areas
IRA	Internationally recognized areas
KBA	Key biodiversity areas
kWh	Kilowatt hour
LCOE	Levelized cost of energy
LLD	Loss of Load Duration
LOLE	Loss of Load Expected
LPA	Legally protected areas
MAF	Mid-term adequacy forecast
MVAC	Medium voltage alternating current
MW	Megawatt
MWh	Megawatt hour
NDC	Nationally Determined Contribution
NSIP	Nationally significant infrastructure projects
O&M	Operation and maintenance
OHS	Occupational Health and Safety
OEM	Original equipment manufacturers
OnSS	Onshore substation
OPEX	Operational expenditures
OSS	Offshore substation
OSW	Offshore Wind
OWF	Offshore wind farm
PoC	Point of connection
PPA	Power purchase agreements
PPP	Public private partnership
PtX	Power to X
R&D	Research and development
RE	Renewable energy
ROV	Remotely operated vehicle

SOV	Service operation vessel
SPA	Special protection areas
SS	Electrical power substation
TEU	Twenty-foot equivalent unit
TP	Transition piece
UDL	Uniformly distributed load
UNFCCC	United Nations Framework Convention on Climate Change
US$	United States dollars
VPPA	Virtual power purchase agreement
VRE	Variable renewable energy
WACC	Weighted average cost of capital
WTG	Wind turbine generator
XLPE	Cross-linked polyethylene

COMPANY AND INSTITUTE ACRONYMS AND ABBREVIATIONS:

ADB	Asian Development Bank
BOI	Board of Investment
CEA	Central Environmental Authority
CEB	Ceylon Electricity Board
DEA	Danish Energy Agency
EBRD	European Bank for Reconstruction and Development
ESMAP	Energy Sector Management Assistance Program
EU	European Union
GE	General Electric
GEBCO	General Bathymetric Chart of the Oceans
GWA	Global Wind Atlas
GWO	Global Wind Organisation
HELCOM	The Baltic Marine Environment Protection Commission
IEA	International Energy Agency
IFC	International Finance Corporation
IMCA	International Marine Contractors Association
IMO	International Marine Organization
IPP	Independent power producers
IUCN	International Union for Conservation of Nature
MVOW	MHI Vestas Offshore Wind
NEWA	New European Wind Atlas

OECD	Organisation for Economic Co-operation and Development
OFTO	Offshore Transmission Owner
OSPAR	Convention for the Protection of the Marine Environment of the northeast Atlantic
PUCL	Public Utilities Commission of Sri Lanka
SEA	Sustainable Energy Authority
SGRE	Siemens Gamesa Renewable Energy
TSO	Transmission System Operator
UNECE	United Nations Economic Commission for Europe
UNDP	United Nations Development Programme
UK	United Kingdom
WB	World Bank
WBG	World Bank Group

APPENDIX A — SRI LANKA PRIORITY BIODIVERSITY VALUES

1 INTRODUCTION

The World Bank Group (WBG) commissioned The Biodiversity Consultancy to provide environmental support for the WBG Offshore Wind Development Program. This support includes the completion of early-stage identification of priority biodiversity values and available spatial data to inform the offshore wind country road map for Sri Lanka. Incorporating considerations of priority biodiversity values in the assessment of 'practical potential' for offshore wind development is essential to avoid adverse impacts from inappropriate development and provide a foundation for a pipeline of bankable projects eligible for funding by International Finance Institutions.

The World Bank (WB) and International Finance Corporation (IFC) environment and social requirements are integral to the Offshore Wind Development Program, and the production of individual country roadmaps. They enable WB, IFC, and client countries to better manage the environmental and social risks of projects, and to improve development outcomes. The WB Environmental and Social Framework, and the IFC Sustainability Framework promote sound environmental and social practices, transparency and accountability. These frameworks define client responsibilities for managing risks and ensure that offshore wind sector preparatory work is aligned with good international industry practice (GIIP). Of particular relevance to this study are:

- WB Environmental and Social Standard 6 (ESS6) Biodiversity Conservation and Sustainable Management of Living Natural Resources (2018), together with the associated Guidance Note ESS6 (2018); and
- IFC Environmental and Social Performance Standard 6 (PS6): Biodiversity Conservation and Sustainable Management of Living Natural Resources (2012), together with the associated Guidance Note 6 (2019).

The objective of this study is to identify priority biodiversity values and areas that support these values that should either be excluded from offshore wind development (i.e., no-go areas), or require additional assessment through subsequent Marine Spatial Planning (MSP), site selection, and Environmental and Social Impact Assessment (ESIA) processes. To meet GIIP, wind developments in areas supporting priority biodiversity values would likely be subject to restrictions in the form of greater requirements for baseline studies, as well more intensive mitigation measures to avoid, minimize and restore adverse environmental impacts. According to IFC PS6 and ESS6, projects situated within critical habitats are required to demonstrate that:

- No other viable alternatives within the region exist for development of the project on modified or natural habitat that are not critical;
- The project does not lead to measurable adverse impacts on those biodiversity values for which the critical habitat was designated, and on the ecological processes supporting those biodiversity values;

- The project does not lead to a net reduction in the global and/or national/regional population of any critically endangered or endangered species over a reasonable period of time; and
- A robust, appropriately designed, and long-term biodiversity monitoring and evaluation program is integrated into the client's management program.

In addition, projects need to achieve net gains of those biodiversity values for which the critical habitat was identified.

This study has focussed on the following key groups of priority biodiversity values, which have been identified through a review of the scientific literature and on experiences in well-developed offshore wind markets:

- Legally Protected Areas (LPAs) and Internationally Recognized Areas (IRAs) - see section 3
- Marine Mammals (cetaceans and pinnipeds) - see section 4
- Birds - see section 5
- Sea Turtles - see section 6
- Fish - see section 7
- Natural Habitats[70] - see section 8

2 METHODOLOGY

For each group of priority biodiversity values, available global and regional spatial datasets were identified and screened for inclusion in one of two spatial data layers for use in the country roadmap:

- **Exclusion zone** (i.e., areas to exclude from the technical assessment of offshore wind resource); and
- **Restriction zone** (i.e., high-risk areas requiring further assessment of risk during MSP, site selection, and/or ESIA).

Numerous global and regional biodiversity datasets exist (primarily produced by academic, scientific and government and non-governmental organizations) and are useful and important resources. Broadly, these datasets provide an indication of the distribution of given biodiversity values. For example, datasets show:

- Verified point records of species occurrence;
- Species range maps;
- The extent of a particular habitat or ecosystem type, or location of key habitat features;
- Modelled indicative habitat suitability; and

70 For the purposes of this study, marine benthic invertebrates are included as integral components of marine natural habitats.

- The boundaries of globally important LPAs and IRAs that represent areas of high biodiversity conservation value.

Threatened and range-restricted species are the focus of criteria 1 and 2 for the determination of critical habitat, as defined by IFC PS6 and therefore represent priority biodiversity values. As a foundational stage, the IUCN Red List was screened to identify all threatened and all range-restricted[71] marine species with global ranges that overlap with Sri Lanka's Exclusive Economic Zone (EEZ). Threatened and range-restricted species are the focus of criteria 1 and 2 for the determination of critical habitat, as defined by IFC PS6 and therefore represent priority biodiversity values. A detailed literature search was completed to identify spatial data and additional contextual information on these species. In addition to identifying digitized spatial data, supplementary data sources were identified and are summarized in the following subsections. In addition to informing this country roadmap, the available secondary data is vitally important to inform future MSP, site selection, and ESIA stages of offshore wind development.

3 LEGALLY PROTECTED AREAS AND INTERNATIONALLY RECOGNIZED AREAS

LPAs and IRAs represent high-value areas designated for various biodiversity conservation objectives, and some should be excluded from consideration for offshore wind development because of this. For example, development in Key Biodiversity Areas (KBAs – see section 3.3) should be avoided because these sites represent the most important places in the world for species and their habitats[72]. In UNESCO Natural and Mixed World Heritage Sites[73], and Alliance for Zero Extinction (AZE) sites, WBG/IFC standards prohibit development (IFC 2012). Other types of designated area, such as Ecologically or Biologically Significant Marine Areas (EBSAs, see section 3.4), may be much larger spatial designations and offshore wind development may be feasible if it is carefully managed and development activities are coordinated to avoid key sensitive periods for biodiversity.

3.1 Nationally Protected Areas

A protected area is a clearly defined geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (IUCN Definition 2008). They are afforded varying levels of legal protection in different national jurisdictions — however, they are often underpinned by commitments made under international conventions.

71 Range-restricted marine species are defined by IFC PS6 as having an extent of occurrence less than 100,000km^2.

72 Keybiodiversityareas.org

73 There are no UNESCO Natural and Mixed World Heritage Sites designated in Turkey with marine components.

The LPA system in Sri Lanka is declared under the Fauna and Flora Protection Ordinance. LPAs in Sri Lanka account for 26.5 percent of the total area of the country. There are a range of LPA types, which are aligned with the IUCN management categories[74], and include the following[75]:

- Strict nature reserves
- National parks
- Nature reserves
- Jungle corridors
- Marine national parks
- Buffer zones
- Managed elephant reserve
- Sanctuaries

Of these, marine national park, nature reserves, and sanctuaries are marine, or have marine components, with 27 LPAs covering a total of 100,966 hectares of marine area[76] (Figure 1 and Table 1). A Marine National Park is defined as an area which includes the sea as well as the adjacent coastal belt which predominantly consists of coral reefs, seagrass meadows, and other similarly valuable ecosystems. Entry into a nature reserve is not permitted. A sanctuary is an area for human activity, but this activity will be subject to regulations. A sanctuary conveys the lowest form of protection when compared to other protection statuses.

It is unlikely that offshore wind development would be compatible with the conservation objectives of the marine national parks or nature reserves and therefore they have been included in the exclusion zone. Although human activity is permitted in sanctuaries, due to the likely sensitivity of the priority biodiversity values from impacts from offshore wind development, they are also included in the exclusion zone. Other types of LPA only cover terrestrial non-marine areas and therefore not included in the scope of the study.

74 https://www.iucn.org/theme/protected-areas/about/protected-area-categories

75 http://lk.chm-cbd.net/?page_id=302

76 http://iucnsrilanka.org/conservation-sri-lanka/marine-protected-areas/

FIGURE 1: PROTECTED AREAS IN SRI LANKA.

TABLE 1: PROTECTED AREAS IN SRI LANKA WITH MARINE COMPONENTS[77].

Legally Protected Area	Total Declared Area (ha)	Marine Area (ha)	Percentage of Declared Area that is Marine
Hikkaduwa Marine National Park	102	102	100%
Pigeon Island Marine National Park	471	471	100%
Adam's Bridge Marine National Park	18,990	18,990	100%
Delft Island National Park (includes a 100m wide belt of near shore waters)	1,846	124	6.71%
Ussangoda National Park (includes a 500m wide belt of near shore waters)	349	200	57%
Chundikulam National Park	19,565	8,606	43%
Nayaru Nature Reserve	4,464	1,157	25%
Nandikadal Nature Reserve	4,142	3,602	87%
Nagarkovil Nature Reserve	7,882	5,242	66%
Vidathalthive Nature Reserve	29,180	22,412	77%
Paraitive Sanctuary	97	97	100%
Great Sobar Island Sanctuary	65	65	100%
Little Sobar Island Sanctuary	6	6	100%
Rumasala Sanctuary	171	160	94%
Rocky Island Sanctuary	1	1	100%
Bar reef Sanctuary	30,670	30,670	100%
Vankalai Sanctuary	4,839	3,014	62%
Rekawa Sanctuary (includes a 500m wide belt of near shore waters)	271	226	83%
Godawaya Sanctuary (includes a 500m wide belt of near shore waters)	231	192	83%
Kokilai Sanctuary	1,995	1,995	100%
Seruwila-Allei Sanctuary	15,540	611	3.90%
Kudumbigala Panama Sanctuary	6,534	338	5%
Nimalawa Sanctuary	1,066	36	3.40%
Kalametiya Sanctuary	2,525	338	13%
Yala National Park	241,868	252	0.10%
Kumana National Park	88,129	353	0.40%
Bundala National Park	9,138	1,706	18%

77 Data shared by the Department of Wildlife Conservation (2018) with the Dugong and Seagrass Conservation Project — Sri Lanka, source: http://iucnsrilanka.org/conservation-sri-lanka/marine-protected-areas/

3.2 Ramsar Sites

Ramsar sites are wetlands of international importance that have been designated under the criteria of the Ramsar Convention on Wetlands for containing representative, rare, or unique wetland types, or for their importance in conserving biological diversity. Contracting parties are expected to manage their Ramsar Sites to maintain their ecological character and retain their essential functions and values for future generations. There are six Ramsar sites designated in Sri Lanka, one of which encompasses marine components: Vankalai Sanctuary[78]. This site supports high ecosystem and species diversity. The wetland is important for many waterbird species including annual migrants. Other important biodiversity features include over 60 species of fish as well as feeding and breeding grounds for rare and threatened species such as marine turtles and dugongs.

It is unlikely that offshore wind development is compatible with maintaining Ramsar sites' ecological character and function and therefore Vankalai Sanctuary Ramsar Site has been included in the exclusion zone layer.

3.3 Key Biodiversity Areas

KBAs have been designated to cover the most important places in the world for species and their habitats. KBAs are identified using a global standard that include criteria that were developed through a multi-stakeholder process. These criteria include quantitative thresholds that mean that sites are globally important for the long-term survival of biodiversity. KBA identification is rigorous, transparent, and can be applied consistently in different countries and over time.

Sites qualify as global KBAs if they meet one or more of 11 criteria, clustered into five higher level categories: threatened biodiversity, geographically restricted biodiversity, ecological integrity, biological processes, and irreplaceability[79]. The KBA criteria are broadly aligned with IFC PS6 criteria for critical habitat, although KBA criteria are wider, and therefore not all KBAs will qualify as critical habitat. All existing BirdLife International Important Bird Areas (IBA) qualify as KBAs (see section 3.3.1). All existing Alliance for Zero Extinction (AZE) sites are also KBAs.

Sri Lanka has 12 designated KBAs with marine components. The majority of these are found on the north and west coasts. Jafna Lagoon (Key Biodiversity Areas Partnership 2020a), Araly South-Punalai (Key Biodiversity Areas Partnership 2020b), and Kayts Island-Mandathive (Key Biodiversity Areas Partnership 2020c) are clustered in the north, emphasising the importance of this area for biodiversity. These areas all support mangroves and saltmarsh which are vital for marine fauna as well as bird life. Two KBAs, Bundala complex and Yala, on the southeast coast are important areas for the Lesser Adjutant (*Leptoptilos javanicus* — IUCN Vulnerable). The population and ecology of this species is poorly understood in Sri Lanka. However, they are migratory and are known to breed on the island (De Silva *et al.* 2015).

Designation as a KBA does not confer legal protection. However, the IUCN recommends that environmentally damaging industrial activities and infrastructure should be avoided within KBAs[80] and therefore all KBAs have been included within the exclusion zone layer.

78 https://rsis.ramsar.org/sites/default/files/rsiswp_search/exports/Ramsar-Sites-annotated-summary-Sri-Lanka.pdf?1618474853

79 http://www.keybiodiversityareas.org/working-with-kbas/proposing-updating/criteria

80 https://portals.iucn.org/library/sites/library/files/resrecfiles/wcc_2016_rec_102_en.pdf

3.3.1 Important Bird Areas

The BirdLife Global Seabird Programme has identified Marine IBAs that include seabird breeding colonies, foraging areas around breeding colonies, non-breeding (usually coastal) concentrations, migratory bottlenecks, and feeding areas for pelagic species. The methodology for the designation of marine IBAs is described in the marine IBA tookit (BirdLife International 2010). Sri Lanka has no marine areas IBAs[81]. However, there are several coastal IBAs that include marine bird species in their designation. These include:

- Jafna Lagoon (Spot-billed, *Pelican Pelecanus philippensis*), Periyakalapuwa mouth (Curlew Sandpiper, *Calidris ferruginea*);
- Mundel Lake (Marsh Sandpiper, *Tringa stagnatilis*; Garganey, *Spatula querquedula*);
- Anaiwilundawa complex (Spot-billed Pelican, *P. philippensis*);
- Bundala complex (Lesser Adjutant, *Leptoptilos javanicus*; Spot-billed Pelican, *P. philippensis*); and
- Yala (Lesser Adjutant, *L. javanicus*; Spot-billed Pelican, *P. philippensis*; Oriental Darter, *Anhinga melanogaster*).

All KBAs, including IBAs, have been included within the exclusion zone layer.

3.4 Ecologically or Biologically Significant Areas

EBSAs are special areas in the ocean that support the healthy functioning of oceans and the many services that it provides. The Conference of the Parties (COP 9) to the Convention on Biological Diversity adopted the following seven scientific criteria for identifying EBSAs: uniqueness or rarity, special importance for life history stages of species, importance for threatened, endangered, or declining species and/or habitats, vulnerability, fragility, sensitivity, or slow recovery, biological productivity, biological diversity, and naturalness. The identification of EBSAs and the selection of conservation and management measures is a matter for states and competent intergovernmental organizations, in accordance with international law (including the UN Convention on the Law of the Sea). The criteria do not include quantitative thresholds, but in principle they have a lot in common with WBG/IFC Natural Habitats definition and critical habitat criteria, and could therefore constitute and important high-level planning consideration for offshore wind development.

There are four EBSAs (Convention on Biological Diversity 2016) in Sri Lanka:

- Sri Lankan side of Gulf of Mannar;
- The southern coastal and offshore waters between Galle and Yala National Park;
- Coastal and offshore area of the Gulf of Mannar; and
- Trincomalee Canyon and associated ecosystems.

The important features recognized in each of these EBSA designations are summarised in Table 2.

81 http://datazone.birdlife.org/country/sri-lanka/marine

Due to the large spatial extent of the EBSA and lack of detailed spatial information on the distribution of their biodiversity values, all four EBSAs are included in the restriction zone layer. However, additional survey data is required to better assess whether offshore wind development is appropriate within the EBSA.

TABLE 2: EBSAS IN SRI LANKA (CONVENTION ON BIOLOGICAL DIVERSITY, 2016).

EBSA	Marine Mammals	Turtles	Birds	Fish	Natural Habitats
The southern coastal and offshore waters between Galle and Yala National Park	The area is particularly important For pygmy blue whales (*Balaenoptera musculus brevicauda*) as well as Bryde's whales (*Balaenoptera brydei*). Unlike other populations of pygmy blue whales, residents do not migrate to cooler waters, but remain in the area year-round to feed. The area also supports sperm whales (*Physeter macrocephalus*), humpback whales (*Megaptera novaeangliae*) and Risso's dolphins (*Grampus griseus*).	The area supports populations of five species of sea turtle. Of these, the hawksbill turtle (*Eretmochelys imbricata*) is listed as critically endangered, and the green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles endangered. Turtles use this area to migrate to and from nesting sites and to mate.	n/a	Many important fishery species including skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*), swordfish (*Xiphias gladius*), sailfish, and marlins (*Istiophorus*) are supported by the area. Juvenile whale sharks (*Rhincodon typus*), manta (genus *Manta*), and mobula (family Mobulidae) rays have been sighted in the area.	Highly productive upwelling system.
Sri Lankan side of the Gulf of Mannar	Globally endangered marine mammal species including the blue whale (*Balaenoptera musculus*) and dugong (*Dugong dugong*) have been recorded in the area.	This coastline is important for endangered species of sea turtles, likely due to the seagrass and mangroves ecosystems which function as feeding grounds.		This area supports a substantial diversity of fish, sharks, and rays.	This stretch of coastline harbour fragile and sensitive ecosystems such as coral reefs, seagrass beds, mangroves, estuaries, and mudflats. Traditionally important natural pearl beds are also located here.
Coastal and offshore area of the Gulf of Mannar	Seagrass in the area provides important feeding and nursery grounds for dugong (*D. dugong*) and other large marine mammals.	The Gulf of Mannar is an important foraging and migratory route for olive ridley (*Lepidochelys olivacea*).	n/a	n/a	Coral reefs, mangroves, and seagrass beds.

EBSA	Marine Mammals	Turtles	Birds	Fish	Natural Habitats
Trincomalee Canyon and associated ecosystems	The area is important for 11 species of cetaceans: two species of baleen whales – blue whale (*B. musculus*) and Bryde's whale (*Balaenoptera edeni*); and nine species of toothed whales – sperm whale (*P. macrocephalus*), killer whale (*Orcinus orca*), dwarf sperm whale (*Kogia sima*), Longman's beaked whale (*Indopacetus pacificus*), false killer whale (*Pseudorca crassidens*), rough-toothed dolphin (*Steno bredanensis*), bottlenose dolphin (*Tursiops truncatus*), striped dolphin (*Stenella coeruleoalba*), and spinner dolphin (*Stenella longirostris*).	Five species of sea turtles rely on the area for foraging, nesting, and as a migratory route: green turtle (*C. mydas*), olive ridley turtle (*L. olivacea*), hawksbill turtle (*E. imbricata*), loggerhead turtle (*C. caretta*), and leatherback turtle (*Dermochelys coriacea*).	n/a	The area supports whale sharks (*R. typus*).	Coral reef habitats, mud flats, fjords, and an important multiple submarine canyon complex.

3.5 Important Marine Mammal Areas

Important Marine Mammal Areas (IMMAs) are a joint project between the IUCN Species Survival Commission (SSC) and World Commission on Protected Areas (WCPA) (IUCN-MMPATF 2019). IMMAs are defined as discrete portions of habitat, important to marine mammal species, that have the potential to be delineated and managed for conservation. IMMAs are designated using standard criteria, through the organization of regional expert workshops:

- Criterion A – Species or Population Vulnerability: Areas containing habitat important for the survival and recovery of threatened and declining species.
- Criterion B – Distribution and Abundance
  - Sub-criterion B1 – Small and Resident Populations: Areas supporting at least one resident population, containing an important proportion of that species or population, that are occupied consistently.
  - Sub-criterion B2 – Aggregations: Areas with underlying qualities that support important concentrations of a species or population.
- Criterion C – Key Life Cycle Activities
  - Sub-criterion C1 – Reproductive Areas: Areas that are important for a species or population to mate, give birth, and/or care for young until weaning.
  - Sub-criterion C2 – Feeding Areas: Areas and conditions that provide an important nutritional base on which a species or population depends.

- Sub-criterion C3 – Migration Routes: Areas used for important migration or other movements, often connecting distinct life-cycle areas or the different parts of the year-round range of a non-migratory population.

- Criterion D – Special Attributes
  - Sub-criterion D1 – Distinctiveness: Areas which sustain populations with important genetic, behavioral or ecologically distinctive characteristics.
  - Sub-criterion D2 – Diversity: Areas containing habitat that supports an important diversity of marine mammal species.

The criteria have quantitative thresholds that are aligned with both IUCN standard for the identification of KBAs (IUCN 2016), and IFC PS6 criteria for critical habitat. Therefore, IMMAs should generally meet IUCN KBA and potentially IFC Critical Habitat criteria. There are two IMMAs in Sri Lanka, for which the IMMA qualifying criteria and species are summarized in Table 3:

- The southwest to eastern Sri Lanka IMMA, located on the southwest to eastern coasts of the island; and

- The Gulf of Mannar and Palk Bay IMMA.

Southwest to eastern Sri Lanka IMMA is a critical feeding, breeding, and calving area for blue whale, sperm whale, and spinner dolphin. The global population of blue whales is estimated at 5,000–15,000 (IUCN 2018) and the Sri Lankan resident population at 600–1,500 mature individuals (Cheng 2019). This area is therefore likely to qualify as critical habitat, as 10-12 percent of the global population reside in the area. The IMMA also supports a wide species diversity. There is a large degree of overlap between the IMMA and marine protected areas, although the IMMA extends over a much larger sea area. Due to a lack of detailed information on the spatial distribution of whale populations within this large area, this IMMA is included within the restriction zone. However, additional survey data is required to better assess whether offshore wind development is appropriate within this IMMA.

The Gulf of Mannar and Palk Bay IMMA is designated for dugong. Although the IMMA only covers 0.32 percent of the dugong range, with less than 300 individuals left in South Asia, any areas used by dugong for feeding, breeding, and calving is of high regional significance. Offshore wind development poses a number of risks to the dugong population, of which disturbance is possibly of most concern. Although data on dugong auditory ability is lacking, dugong auditory sensitivity is estimated to fall between the low-frequency and mid-frequency cetaceans (Kent *et al.* 2009). However, dugong response time is slow, often resulting in boat strikes even by slow moving vehicles. Dugongs have been found to react to high-speed outboard boat motors at 150m distance and aircraft engines from 300m, but are able to habituate to boat noises in busy harbours. There is a lack of studies on the impacts of piling-related noise impacts on dugong, however there are studies on Phocid seals that provide an indication of potential impacts. (Faulkner *et al.* 2019) predicted that Phocid seals would suffer permanent hearing loss (termed Permanent Threshold Shift, PTS) up to 2.4km from pile driving. (Russell *et al.* 2016), recorded significant temporary displacement in Harbour Seal of up to 25km from the center of the wind farm during piling. Reassessment of the data from (Russell *et al.* 2016) was completed by (Whyte *et al.*. 2020). This predicted that four of the 24 tracked seals received noise levels that exceeded the threshold at which PTS would occur and twelve were predicted to exceed the threshold for temporary hearing loss (termed Temporary Threshold Shift, TTS). PTS thresholds were exceeded between 3.9 and 6.9 km from piling activities, and TTS thresholds were exceeded up to 17km away. In a separate study, a significant reduction in seal numbers was observed at Rødsand seal sanctuary, situated ten kilometers from the piling activity (Edrén et al. 2004). Noise propagation distances from piling will vary according to site-specific factors such as bathymetry, substrate, and pile type – as well as potential mitigation measures that might be employed (e.g., bubble curtains). There is a need for further research and assessment, but given the potential risk to dugongs from underwater noise, disturbance is likely to be significant if unmitigated piling takes place.

The basis for the delineation of the boundaries of the Gulf of Mannar and Palk Bay IMMA is not known, but extends significantly beyond the areas of mapped seagrass beds (see section 8.2). Therefore, Gulf of Mannar and Palk Bay IMMA is provisionally treated as a Restricted Zone, but any proposed wind development within 25km of surrounding seagrass beds would likely be high risk with respect to potential impacts on dugong, and require careful assessment prior to the siting of proposed offshore wind developments.

TABLE 3: IMMAS IN SRI LANKA.

IMMA	Area (km^2)	Primary Species	IMMA Criteria[82]	Additional Species - (IMMA Criterion D (ii) Diversity)
Southwest to eastern Sri Lanka[83]	28,699	Sperm Whale *Physeter macrocephalus*	A; B (2); C (1, 2)	*Balaenoptera edeni, Balaenoptera omurai, Stenella attenuata, Stenella coeruleoalba, Tursiops truncatus, Steno bredanensis, Lagenodelphis hosei, Grampus griseus, Globicephala macrorhynchus, Peponocephala electra, Pseudorca crassidens, Feresa attenuata, Orcinus orca, Kogia sima, Kogia breviceps*
		Blue Whale *Balaenoptera musculus*	A; B (2); C (1, 2)	
		Spinner Dolphin *Stenella longirostris*	B (2); C (1, 2)	
Gulf of Mannar and Palk Bay[84]	20,663	Dugong *Dugong dugon*	A; B (1); C (2)	

82 https://www.marinemammalhabitat.org/immas/imma-criterial/

83 https://www.marinemammalhabitat.org/portfolio-item/southwest-east-sri-lanka/

84 https://www.marinemammalhabitat.org/portfolio-item/gulf-mannar-palk-bay/

4 MARINE MAMMALS

Sri Lanka supports a high diversity of marine mammals, with 27 species recorded to date. Of these, six are assessed as globally threatened (Table 4). Marine mammals feature prominently in the designations of several overlapping LPAs and IRAs as described in section 3, particularly the two IMMAs and four EBSAs. Digitized spatial datasets in addition to those listed in section 3 were not found for marine mammals, although there are additional survey and sighting data available that would be useful to inform MSP, site selection, and ESIA. It is likely that the majority of the important areas for marine mammals are included in designated PA and IRAs.

TABLE 4: THREATENED MARINE MAMMALS OCCURRING IN SRI LANKA.

Latin Name	Common Name	IUCN Threat Status	Global Range Area (km^2)
Balaenoptera musculus	Blue Whale	EN	434,753,529
Sousa plumbea	Indian Ocean Humpback Dolphin	EN	493,077
Dugong dugon	Dugong	VU	6,469,966
Neophocaena phocaenoides	Indo-Pacific Finless Porpoise	VU	2,946,071
Physeter macrocephalus	Sperm Whale	VU	347,262,853
Sousa chinensis	Indo-Pacific Humpback Dolphin	VU	1,074,612

5 MARINE TURTLES

There are five threatened species of marine turtles with global ranges that overlap with the Sri Lanka EEZ: olive ridley turtle (*Lepidochelys olivacea*), green turtle (*Chelonia mydas*), hawksbill turtle (*Eretmochelys imbricata*), leatherback turtle (*Dermochelys coriacea*), and loggerhead turtle (*Caretta caretta*) (Table 5).

TABLE 5: THREATENED MARINE TURTLES OCCURRING IN SRI LANKA.

Latin Name	Common Name	IUCN Threat Status	Global Range Area (km^2)
Lepidochelys olivacea	Olive Ridley	VU	79,530,390
Eretmochelys imbricata	Hawksbill Turtle	CR	276,653,106
Chelonia mydas	Green Turtle	EN	176,482,666
Dermochelys coriacea	Leatherback	VU	216,124,441
Caretta caretta	Loggerhead Turtle	VU	271,358,117

Green turtles and olive ridley turtles are the most abundant species of turtle along the coasts of Sri Lanka. These two species account for the majority of nesting sites, with 68 percent and 30 percent respectively in 2014 (Jayathilaka *et al.* 2017) five species were reported in the coastal belt of Sri Lanka coming for nesting: green turtle (*Chelonia mydas*). Both species are known to nest at many sites across the southwestern to the southeastern coast (Table 6). Little is known about hawksbill, leatherback, and loggerhead turtles in Sri Lanka; however, they have been observed nesting at a small number of beaches (Table 6). Sri Lankan loggerhead turtles do not interbreed with those elsewhere and are considered a separate management unit (Hamann *et al.* 2013). As loggerhead turtles are not known to nest in the northeastern Indian Ocean (Hamann *et al.* 2013), Sri Lankan nesting sites are regionally important for the species.

Although turtle nesting beaches are distributed across the entire coastline, except in Puttalam and Gampaha districts, the primary nesting beaches can be found on the west, south, and the southeastern coasts. Galle and Hambantota districts in particular harbour the most used nesting beaches. Marine turtle nesting beaches feature in the designations of LPAs and EBSAs as described in section 3. However, there are also many important nesting sites along the west coast which are not covered by these designations. The locations of nesting beaches have been digitized from the following sources, Jayathilaka *et al.* 2017; Department of Wildlife Conservation (DWC), Sri Lanka; Biodiversity Education And Research (BEAR) five species were reported in the coastal belt of Sri Lanka coming for nesting: green turtle (*Chelonia mydas*), which are included in the exclusion zone. Tracking studies have shown that the neritic areas up to 10km either side of a nesting beach are important habitat for both green and loggerhead turtles (possibly limited to 1-2km from the coast for green turtle and 5km for loggerhead (Tucker *et al.* 1995; Schofield *et al.* 2010; Waayers *et al.* 2011)), and for juvenile turtles making their way to the ocean post-hatching. The identified nesting beaches, plus a 5km buffer are included within the exclusion zone.

Information on sea turtle foraging or migratory behavior areas in Sri Lanka is limited (Nel 2012; Hamann & Limpus 2019). Offshore near Kandakuliya, thousands of olive ridley turtles aggregate each year without nesting in the area. Loggerhead turtles have been observed foraging off the Gulf of Mannar (Hamann *et al.* 2013). Hawksbill turtles have been observed foraging in seagrass beds, coral reefs, and rocky reefs. No information about their foraging or migratory behavior for Sri Lanka was found.

TABLE 6: MAJOR NESTING BEACHES*.

Location	Green Turtle	Olive Ridley Turtle	Hawksbill Turtle	Leatherback Turtle	Loggerhead Turtle
Ahungalla	✓	✓	✓		
Akurala	✓				
Ambalangoda	✓	✓			
Ambalantota	✓			✓	
Balapitiya	✓	✓			
Benthota	✓	✓			
Bundala	✓	✓	✓	✓	✓
Duwemodar	✓	✓			
Habaraduwa	✓	✓			
Kahawa	✓	✓	✓		
Koggala	✓	✓		✓	
Kosgoda	✓	✓	✓	✓	✓
Mahapalana	✓	✓		✓	✓
Mavela	✓			✓	
Mount Lavania	✓	✓	✓		
Induruwa	✓	✓		✓	
Rekawa	✓	✓	✓	✓	✓
Usangoda	✓	✓		✓	
Warahena	✓	✓			
Wedikanda	✓				
Yala	✓	✓		✓	

*Sources: (Rajakaruna *et al.* 2009; Department of Wildlife Conservation (DWC), Sri Lanka 2014; Jayathilaka *et al.* 2017)

6 BIRDS

6.1 Seabird Breeding Colonies

Sand Island III (9.067°N 79.633°E) is a four-hectare island to the west of Mannar Island and is the most important island for seabird breeding in Sri Lanka. This is the only known breeding colony in Sri Lanka for many seabirds including sooty tern (*Onychoprion fuscatus*), bridled tern (*Sterna anaethetus*), Saunders's tern (*S. saundersi*), roseate tern (*Sterna dougallii*), common tern (*S. hirundo*), and brown noddy (*Anous stolidus*) (Asian Development Bank (ADB) 2017). Both greater crested tern (*Thalasseus bergii*) and little tern (*Sternula albifrons*) also make use of this area as a breeding colony (*Asian* Development Bank (ADB) 2017). Sand Island III is located within Adam's Bridge Marine National Park and has therefore been included in the exclusion zone.

No additional digitized spatial data was found in relation to breeding seabird species; however the following sub-sections makes references to studies that provide survey and sightings data available that would be useful to inform MSP, site selection and ESIA.

6.2 Flyways / Bottlenecks

The greatest threat to migratory seabirds from offshore wind development is collision with turbines. The west coast, from the Guld of Mannar southwards, is particularly important for migratory seabirds with up to 400,000 birds flying southwards during daytime (De Silva 1997). During the southwest monsoon from June/July to October/November a mass migration of bridled terns occurs, joined by other species such as wedge-tailed shearwater (*Puffinus pacificus*), Wilson's storm-petrel (*Oceanites oceanicus*), lesser frigatebird (*Fregata ariel*), brown skua (*Catharacta antarctica*), pomarine skua (*Stercorarius pomarinus*), brown noddy, (*Anous stolidus*), and lesser noddy (*Anous tenuirostris*).

In the inter-monsoonal period (October/November) a large number of Wilson's storm-petrels (*Oceanites oceanicus*) arrive in Sri Lanka. This species likely uses the west coast as a staging area before continuing on to breeding areas in Antarctica (De Silva 1997). During this period many winter visitors, such as the black tern (*Chlidonias niger*) also arrive along the west coast. June/July brings the only summer breeding visitor, the roseate tern, which nest on the west coast. The width of the migratory corridor for seabirds along the west coast is unknown; however, large numbers of migratory seabirds are visible from land based vantage points along the west coast, including Talawila, Chilaw, Negombo, Colombo (and its coastal suburbs), Beruwela, Bentota, Ambalangoda, Hikkaduwa, and Galle.

For non-marine migratory bird species, the greatest threat from offshore wind stems from collision with turbines located on migratory bottlenecks. Sri Lanka is situated on the Central Asian/South Asian flyway. Over 300 species migrate along the Central Asian Flyway including several species that undertake regular, seasonal movements within the Indian subcontinent. Among these are the indian pitta (*Pitta brachyura*), pied thrush (*Zoothera wardii*), and kashmir flycatcher (*Ficedula subrubra*) (VU), all of which winter in southern India and Sri Lanka (BirdLife International n.d.). Despite a wealth of information for other flyways, data is lacking for Sri Lanka regarding the seasonal composition of migratory waves (Kotagama *et al.* 2006). Sri Lanka is also important for the East Asia-Australasian flyway as birds migrate around the Indo-Malay peninsula and down the east Asian coastline to congregate at a small number of sites, including Sri Lanka (Bamford *et al.* 2008).

Non-marine migratory birds enter Sri Lanka through several entry points. The major entry points include Adam's Bridge and Mannar (Asian Development Bank (ADB) 2017). Adam's Bridge provides one of the important entry points intro Sri Lanka for thousands of migratory birds arriving through the East Asian-Australasian Flyway. These birds either enter Mannar from Jaffna peninsula or through Rameswaram via Adam's Bridge. It is likely that many weak fliers follow Adam's Bridge when entering Sri Lanka to avoid wide water crossings. Mannar is also a key entry and exit point for migratory birds using the Central Asian Flyway. The birds then disperse into the wetland habitats of the area, which are highly ecologically significant for annual migrants, providing feeding grounds and wintering sites for many waterbirds. This area therefore plays an important role in Sri Lanka for migratory birds (Asian Development Bank (ADB) 2017).

No additional digitized spatial data was found in relation to migratory bird species; however, it is clear that the whole west coast of Sri Lanka is very important for migratory seabirds.

6.3 Threatened Marine Birds in Sri Lanka

Only three threatened marine bird species have IUCN global ranges that overlap with Sri Lanka EEZ (Table 7), including a single true seabird (Procellariidae) species — trindade petrel (*Pterodroma arminjoniana* – vulnerable). However, there is no further published information about the trindade petrel's use of Sri Lanka as feeding, breeding, or migratory areas. The spoon-billed sandpiper (*Calidris pygmaea* — critically endangered) was spotted for the first time in Sri Lanka in over 40 years in 2018 at Vankalai Sanctuary[85]. The lesser adjunct (*Leptoptilos javanicus* – vulnerable) is known to breed on the island but active nests are rarely observed. They are largely restricted to the dry lowland areas on Sri Lanka, including coastal wetlands (De Silva *et al.* 2015). No additional digitized spatial data was found in relation to threatened bird species.

TABLE 7: THREATENED MARINE BIRD SPECIES OCCURRING IN SRI LANKA.

Latin Name	Common Name	IUCN Threat Status	Global Range Area (km^2)
Calidris pygmaea	Spoon-billed Sandpiper	CR	537,244
Leptoptilos javanicus	Lesser Adjutant	VU	3,076,578
Pterodroma arminjoniana	Trindade Petrel	VU	47,405,599

85 https://migrantwatch.wordpress.com/2018/06/25/spoon-billed-sandpiper-found-in-sri-lanka/

7 FISH

According to the IUCN Red List, there are 21 threatened bony fish and 66 threatened cartilaginous fish species whose global ranges overlap the Sri Lankan EE, of which 16 cartilaginous fish are critically endangered.

Very few LPA and IRA designations (section 3) include fish as specific features of interest, although many include habitats that are likely important to fish. Fish are identified as important features of the two of the three Sri Lankan EBSAs. The southern coastal and offshore waters between Galle and Yala National Park is designated for important fishery species, and the Trincomalee Canyon and associated ecosystems for whale shark (Table 2). No additional digitized spatial data has been identified in relation to fish.

8 NATURAL HABITATS

8.1 Threatened Natural Habitats

Although Sri Lanka has no official list of threatened natural habitats, several ecosystems are highly important both ecologically and economically for the country. This includes pearl mussel beds, seagrass beds, mangroves, coral reefs, and coastal sand dunes.

- **Pearl beds**: The Gulf of Mannar is one of the most abundant sources of natural pearls globally (Katupotha 2019), making this area of high economic and ecological importance to Sri Lanka. To the north, Palk Bay and the Gulf of Kutch are also important pearl bed resources for India. In the Gulf of Mannar, these pearl beds are concentrated along the coastline from Mannar Island in the north to Kalpitiya in the south. While there is no digitized spatial information, available maps show that pearl beds fall within the Gulf of Mannar EBSA, which is therefore included in the restriction zone.

- **Seagrass**: Seagrass beds support high biodiversity and provide essential ecosystems (Duarte *et al.* 2008; Bertelli & Unsworth 2014) forming extensive habitats which support highly diverse communities. The seagrasses themselves assimilate and cycle nutrients and other chemicals. Their extensive above- and below-ground biomass traps sediments, reducing coastal turbidity and erosion, as well as providing habitat for other organisms both attached and free-living (Hemminga & Duarte 2000). They provide important feeding, breeding, and nursery grounds for many threatened species, including dugongs and marine turtles. Fifteen species of seagrass are found in Sri Lanka along the western, northwestern, and northern coastline (Pahalawattaarachchi n.d.). Important seagrass resources are clustered along the northwestern coast from Puttalam Lagoon in the Gulf of Mannar to the northern end of Palk Bay. Isolated seagrass beds can also be found on the east coast near Kokkilai Lagoon. Due to their importance for the ecosystem and threatened marine species (especially dugong), the mapped areas of seagrass beds sourced from the Allen Coral Atlas[86] are included in the exclusion zone.

86 https://allencoralatlas.org/

- **Mangroves**: Mangroves are patchily distributed along the entire Sri Lankan coastline (Chandrasekara *et al.* 2016). The largest mangrove areas located in the north, northwestern, and east coasts. Due to the need for freshwater input, they are clustered around lagoons and estuaries. The total extent of mangroves around Sri Lanka has been estimated at 4,000–10,000ha (Jayatissa 2012). They play a key role as nursery areas for a variety of species, including commercially important fish. Much of the mangrove distribution falls within LPAs and IRAs. The mapped areas of mangrove sourced from Clarks Labs[87] are included in the exclusion zone.
- **Coral reef**: Coral reefs are mainly found on the south and northwest coast as well as the east coast at Trincomalee. Coral reefs are essential for many threatened marine species in Sri Lanka, including sea turtles dugongs, and a diversity of fish species. While the majority of offshore reefs are undamaged, the near-shore reefs have low coral cover due to damage by human activities, including coral mining and destructive fishing practices (Linden & Sporrong 1999). Coral reef hotspots include Jafna Peninsular, the Gulf of Mannar, Negombo, Hikkaduwa, Galle, Matara, Basses, Passekudah, and Trincomalee[88]. The majority of the remaining coral reefs lie within LPAs or IRAs. The mapped areas of coral reef sourced from the Allen Coral Atlas are included in the exclusion zone.

8.2 Threatened Marine Benthic Invertebrates in Sri Lanka

Sri Lanka has a total of 65 threatened marine invertebrates, comprising eight species of sea cucumber (Holothuroidea), 56 species of stony coral (*Scleractinia*), and one octocoral (*Helioporacea*). All of these species are covered by the areas mapped as coral reefs, which is included in the exclusion zone.

Fringing coral reef can be found around the coastline. Important coral reef areas include the Gulf of Mannar, Bar Reef Marine Sanctuary, Kandakuliya, Talawila, Chilaw, Negombo, Colombo, Ambalangoda to Hikkaduwa, Hikkaduwa Marine Sanctuary, Galle including Rumassala reef, Unawatuna, Weligama, Polhena, Matara, Tangalle, Great and Little Basses, and Batticoloa and Trincomalee. All of these reefs are at least somewhat damaged by human activities (Rajasuriya 1997).

87 https://clarklabs.org/aquaculture/

88 https://www.slam.lk/corals

9 SUMMARY

Sections 3 to 8 provide the rationale for the digitized spatial data included within the exclusion and restriction zone layers to be taken into account within the Sri Lanka offshore wind roadmap. These are summarised in Table 8 along with the sources of the relevant digitized spatial data.

TABLE 8: SUMMARY TABLE OF DIGITIZED SPATIAL DATA TO BE INCLUDED IN EXCLUSION AND RESTRICTION ZONE.

Zone	Priority Biodiversity value	Available Digitized Spatial Data Layer	Source
Exclusion Zone	LPAs and IRAs	Marine national parks	World Database on Protected Areas (WDPA) Layer provided by Ranil Nanayakkara — original source unconfirmed
		Nature reserves	
		Sanctuaries	
		Ramsar sites	www.ibat-alliance.org
		KBAs, including IBAs and AZE sites	www.ibat-alliance.org
	Marine Turtles	Turtle nesting beaches identified from published literature, plus 5km buffer	Adapted from Rajakaruna *et al.* 2009; Department of Wildlife Conservation (DWC), Sri Lanka 2014; Jayathilaka *et al.* 2017
	Natural Habitats	Seagrass beds Coral reefs	https://allencoralatlas.org/
		Mangroves	https://clarklabs.org/
Restriction Zone	LPAs and IRAs	EBSAs IMMAs	https://www.cbd.int/ http://www.marinemammalhabitat.org/imma-eatlas/
	Marine Mammals (dugong)	25km buffer around seagrass beds	Adapted from seagrass beds layer sourced from https://allencoralatlas.org/

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