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PAKISTAN'S OFFSHORE WIND ENERGY POTENTIAL

Social, Economic and Financial Challenges to its Realization

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Contents

1 Introduction

Pakistan is highly vulnerable to the impacts of climate change, which include increased frequency of extreme weather events, glacial melting, rising sea levels, and heat waves. These changes pose severe risks to the country's agriculture, water resources, socio-economic and ecological stability, and give rise to issues of sustaining livelihoods and communities' displacement. A striking example is the devastating floods of 2022, which displaced millions, damaged infrastructure, and caused economic losses estimated at over $30 billion. Pakistan contributes less than 1% to the global greenhouse gas (GHG) emissions yet faces severe impacts of climate change.[1] Internationally, Pakistan is part of the United Nations Framework Convention on Climate Change (UNFCCC) and has pledged to increase its share of renewable energy in its energy mix to 60 percent by 2030 as part of its Nationally Determined Contributions (NDCs) submitted in 2021[2]. Pakistan, still developing, can rely on a sustainable energy path, and goals set forth in the NDCs can help with staying aligned to this direction.

The International Renewable Energy Agency (IRENA) highlights that Variable Renewable Energy (VRE) can significantly reduce CO2 emissions and help countries meet their climate goals[3]. Pakistan is taking steps towards meeting its energy demands and reducing greenhouse gas emissions. The Government of Pakistan (GoP) is actively pursuing renewable energy investments on a large scale, as part of its clean energy goals. The transition to VRE is critical for Pakistan's energy sector which has been plagued by capacity payments to thermal power plants, and a compounding circular debt. This transition would also allow the country to significantly reduce its greenhouse gas emissions aligning with the goals of the Paris Agreement, as its energy sector is the second largest source of CO_2 emissions at 218.94 $MtCO_2e$.

During fiscal year 2023, the total electricity generation was 92,091 GWh, with hydel contributing 28.11%, nuclear 18.65%, renewables 4.66%, and the majority share of the power mix coming from thermal at 48.57%[4]. The high share of GHG emissions from thermal sources within the energy sector mandates its transition towards VRE and ultimately help Pakistan meet its climate commitments, under its submitted NDCs. The National Electricity Plan, which the Pakistani government unveiled in February 2021, outlined three primary objectives for the electricity sector: sustainability, energy security, and affordable energy availability[5].

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1 https://climatepromise.undp.org/what-we-do/where-we-work/pakistan
2 https://unfccc.int/sites/default/files/NDC/2022-06/Pakistan%20Updated%20NDC%202021.pdf
3 https://www.irena.org/publications/2018/apr/renewable-energy-policies-in-a-time-of-transition
4 https://www.finance.gov.pk/survey/chapter_24/Economic_Survey_2023_24.pdf
5 https://power.gov.pk/SiteImage/Policy/National%20Electricity%20Plan%202023-27.pdf

Pakistan has significant indigenous renewable energy resources, including solar, wind and hydel power. Utilizing these resources can enhance energy security and reduce dependence on imported fossil fuels. According to an Alternate Energy Development Board estimate, Pakistan has the potential to generate over 50,000 MW of wind power[6]. Pakistan has ample physical resource potential to reach its targets for VRE to provide at least 20% of total electricity generating capacity by 2025, and 30% by 2030[7] as per the Alternate and Renewable Energy Policy 2019 (ARE Policy)[8].

According to a World Bank study report, by utilizing only 0.071% of the land for solar and wind energy, especially in Balochistan, Sindh, and southern Punjab, Pakistan can fulfill her energy demand. The study also predicted that increasing solar and wind capacity to at least 30% of total installed capacity by 2030 would represent a "least-cost" expansion scenario, resulting in fuel savings equal to $5 billion over 20 years, increased energy security, and reduced greenhouse gas emissions[9]. These untapped resources could be explored to solve Pakistan's energy security challenges, provided that the grid infrastructure is upgraded to meet the demand.

As of January 31, 2024, wind energy in Pakistan accounts for 4.8% of the country's total generation capacity, with an installed wind capacity of 1,838 MW. Pakistan's wind energy potential is substantial, with conservative estimates indicating around 132 GW of potential overall1. Of this, an exploitable 50,000 MW is concentrated along a 60-180 km stretch of the coastal belt, while the Pakistan Meteorological Department has identified an untapped wind potential of approximately 346,000 MW across the country[10]. Currently, 36 private wind projects contribute nearly 1,845 MW to the national grid[11].

Utilizing existing substation capacity can help achieve the 20% target with minimal grid investment[12]. The VRE market in Pakistan is evolving rapidly, driven by significant efforts to integrate solar and wind power into the national grid. The government, with support from international organizations like the World Bank, is focusing on strategic spatial planning to optimize the use of available land and grid infrastructure. This approach aims to minimize transmission losses and ensure that new VRE projects are economically viable and efficiently integrated into the existing power network[12].

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[6] https://www.trade.gov/country-commercial-guides/pakistan-renewable-energy?form=MG0AV3
[7] https://documents1.worldbank.org/curated/en/883241610741226840/pdf/Main-Report.pdf
[8] https://www.power.gov.pk/SiteImage/Policy/2-AREPolicy2019.pdf
[9] https://documents1.worldbank.org/curated/en/883241610741226840/pdf/Main-Report.pdf
[10] https://link.springer.com/article/10.1007/s11356-020-10869-y
[11] https://www.brecorder.com/news/40319368
[12] https://www.irena.org/publications/2018/apr/renewable-energy-policies-in-a-time-of-transition

The table below shows the total VRE installed and committed capacities, showing significant realizable growth potential in renewable energy across Pakistan.

	Additions until 2023			Additions between 2023 and 2025			Additions between 2025 and 2030		
Province	**Wind**	**Solar**	**Total**	**Wind**	**Solar**	**Total**	**Wind**	**Solar**	**Total**
Sindh	480	700	1,180	900	1,350	2,250	500	950	1,450
Balochistan	800	1,050	1,850	500	650	1,150	4,000	2,150	6,150
Punjab	200	1,310	1,510	0	1,390	1,390	600	1,700	2,300
KPK	0	200	200	50	325	375	0	400	400
VRE Installed and Committed	2,095	1,140	3,235	150	50	200	0	100	100
Total VRE	3,575	4,400	7,975	1,600	3,765	5,365	5,100	5,300	10,400
Total Installed Generation	53,685 MW			61,941 MW			75,595 MW		
Percent VRE of Installed Generation	**14.9%**			**21.5%**			**31.4%**		

Summary of realizable VRE additions potential until 2030 in Pakistan's context

2 Offshore Wind Power: A resource unexplored

2.1 What is offshore wind?

As the word Offshore means ‘at sea some distance from the shore’, the offshore wind energy harnesses the power of wind at sea to generate electricity, providing a renewable resource close to population centers where land availability is limited. The principal motivation for developing offshore wind energy started after realizing effective utility of the abundant wind resources in ocean and lake areas, which was a promising aspect on reducing reliance on land-based turbines.

Usually, wind energy is generated by through a five-stage process, the wind flowing turns the turbine to help the blades rotate, the mechanical energy production from the rotor blades to the shafts and gears, convert to electrical energy with the help of a generator, and taken to a transformer that is provided for the power transmission to the grid.

Offshore wind turbines are strategically placed in areas with higher and more consistent wind speeds, making them an ideal source of renewable energy. Typically located far from shore, offshore wind farms minimize their impact on shipping lanes and human activities. In recent years, offshore wind power has gained popularity due to its potential to produce large amounts of electricity. Larger turbines are used in offshore wind farms, generating more electricity per unit and can be placed in deeper waters where wind is stronger and more consistent, further increasing their potential energy output.

Offshore wind farms are typically built in Shallow Ocean waters, where wind speeds are stronger and more consistent, allowing for optimal energy generation. Presently, most offshore wind farms feature turbines fixed to the seafloor in shallow waters. However, advancements in technology are enabling the development of floating wind farms, which can be situated in deeper waters, further expanding the potential for offshore wind energy production.

Offshore wind farms have several advantages over onshore wind farms. They can generate more energy per turbine due to stronger and more consistent winds, and can produce the same amount of energy with fewer turbines. Additionally, offshore wind farms have fewer environmental impacts, such as noise pollution and land use effects, and can be built larger due to fewer obstacles. Offshore wind power is a renewable and infinite energy source, producing no greenhouse gas emissions during conversion. As the world transitions to green electricity, offshore wind power will play a crucial role in reducing greenhouse gases and ensuring energy affordability, particularly since wind power is cheaper than imported gas.

2.2 How is it different from onshore wind?

The installation of wind turbines, whether situated onshore or offshore, is characterized by a relatively swift deployment compared to other energy sources as they play a playing crucial role in generating clean and affordable energy. Wind energy has demonstrated its capability as a vital contributor to public energy supply, solidifying its position as a crucial element in the energy discourse. Offshore wind turbines harness sea winds for consistent, renewable energy. Onshore wind power uses land-based turbines for clean and reliable energy. Both offer promising renewable energy sources, with offshore turbines tapping into stronger sea winds.

Wind technology has been harnessed both on land and in the sea, the ongoing debate on the comparison between onshore and offshore wind turbines ensures its continued relevance in the energy conversation. Furthermore, as wind power gains prominence as a renewable energy source, researchers expect substantial enhancements in both onshore and offshore wind technologies, driving progress in the field.

The following table provides key differences between both technologies.

Key Differences	
Offshore wind	**Onshore wind**
Location	
Wind turbines are installed in bodies of water, such as oceans or large lakes, typically far from shore. They are typically installed in water depths of 5-50 meters.	Wind turbines are installed on land.
Wind Speed	
Wind speeds are generally higher and more consistent over water, having a higher capacity factor making them ideal for power generation.	Wind speeds can be lower and more variable, depending on terrain and obstacles, they also have a lower capacity factor due to weaker winds.
Turbine Size	

Turbines are typically larger and more powerful to capture the stronger winds and compensate for the higher installation costs.	Wind speeds can be lower and more variable, depending on terrain and obstacles.
Installation & Maintenance Costs	
Installation costs are higher due to the complexity of building in water, transporting equipment, and ensuring durability in harsh marine environments. More challenging and expensive maintenance due to location.	Installation costs are lower, as construction can be done on existing infrastructure and terrain. Easier and less expensive maintenance.
Environmental Impact	
This has a lower visual impact and can be located far from population centers, reducing noise and other concerns.	This can have a higher visual impact and may be closer to residential areas, potentially generating more noise and inconvenience.
Energy Production & Transmission	
This can generate more electricity per turbine due to stronger and more consistent winds. Require longer transmission cables to reach shore.	This may generate less electricity per turbine due to variable wind speeds and turbulence. It requires shorter transmission cables and is easier to integrate into the grid.
Types	
Monopile Wind Turbines, Jacket Wind Turbines, Floating Wind Turbines, Tension Leg Platform (TLP) Wind Turbines, Spar Buoy Wind Turbines	Horizontal Axis Wind Turbines (HAWT, Vertical Axis Wind Turbines (VAWT), Darrieus Wind Turbines, Savonius Wind Turbines, Hybrid Wind Turbines
Scalability & Foundation Type	

Offshore wind farms can be built larger due to fewer land use constraints, they can accommodate larger turbines and they can be expanded to multiple phases or projects.	Offshore wind farms are not easily scalable, they are limited by land availability, nearby communities, environmental concerns and their use constraints, the turbine size and project scale limited by transportation and installation constraints.
There are foundation types of offshore wind turbines: • **Monopile Foundation**: Single, large diameter pile driven into the seabed (typically 2-6 meters in diameter and 20-60 meters long) • **Jacket Foundation**: Lattice-like structure anchored to the seabed (typically 20-50 meters tall and 10-20 meters wide) • **Floating Foundation**: Installed on floating structures that can be placed in deep waters (e.g. spar buoys, tension leg platforms)	There are foundation types of onshore wind turbines: • **Shallow Foundation:** Spread foundation or mat foundation (typically 1-3 meters deep and 5-10 meters wide) • **Pile Foundation:** Driven piles or drilled shafts (typically 10-30 meters deep and 1-2 meters in diameter) • **Caisson Foundation:** Reinforced concrete caissons (typically 5-10 meters deep and 2-5 meters in diameter)

2.3 Cost Benefit Analysis of Offshore wind (Tariffs)

In 2022, global energy markets faced considerable economic challenges, including heightened material and equipment costs. Yet, despite these pressures, the cost of electricity from newly commissioned projects in renewable sectors—such as utility-scale solar photovoltaics (PV), onshore wind, concentrating solar power (CSP), bioenergy, and geothermal—continued to decline. This resilience underscored the economic viability of renewable energy as a stable, cost-effective alternative in an uncertain fossil fuel market.

2.3.1 China's Influence and Market Variations

China played a pivotal role in reducing costs for solar PV and onshore wind, enabling global progress in price reductions for these technologies. However, the results were less uniform in other markets, where economic pressures caused some renewable energy costs to rise. This regional variation highlights the complexity of achieving universally lower renewable energy costs and the influence of localized market dynamics.

	Total installed costs (2022 USD/kW)			Capacity factor (%)			Levelised cost of electricity (2022 USD/kWh)		
	2010	2022	Percent change	2010	2022	Percent change	2010	2022	Percent change
Bioenergy	2 904	2 162	-26%	72	72	1%	0.082	0.061	-25%
Geothermal	2 904	3 478	20%	87	85	-2%	0.053	0.056	6%
Hydropower	1 407	2 881	105%	44	46	4%	0.042	0.061	47%
Solar PV	5 124	876	-83%	14	17	23%	0.445	0.049	-89%
CSP	10 082	4 274	-58%	30	36	19%	0.380	0.118	-69%
Onshore wind	2 179	1 274	-42%	27	37	35%	0.107	0.033	-69%
Offshore wind	5 217	3 461	-34%	38	42	10%	0.197	0.081	-59%

Source: IRENA [13]

2.3.2 Cost Trends Across Renewable Technologies

- Onshore Wind: The global weighted-average levelized cost of electricity (LCOE) for newly commissioned onshore wind projects fell by 5% from 2021 to 2022, reaching USD 0.033/kWh. This decline highlights continued advances in wind technology efficiency and scale.
- Utility-Scale Solar PV: Solar PV costs continued to drop, with the global weighted-average LCOE decreasing by 3% year-on-year to USD 0.049/kWh, a positive trend reflecting improved solar technology and optimized deployment strategies.
- Offshore Wind: In contrast to the cost reductions in onshore wind and solar PV, offshore wind saw a slight increase in cost. The LCOE for newly commissioned offshore wind projects rose by 2%, moving from USD 0.079/kWh in 2021 to USD 0.081/kWh in 2022. This increase can be attributed to unique logistical and technological challenges specific to offshore installations, such as transportation, maintenance, and the complexity of marine infrastructure. Nevertheless, offshore wind remains a critical renewable technology, with substantial potential in high-wind regions and near coastal population centers, offering grid stability and large-scale capacity despite the initial cost hurdles.

[13] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2023/Aug/IRENA_Renewable_power_generation_costs_in_2022.pdf

2.3.3 Renewable Energy as a Shield Against Fossil Fuel Volatility

The fossil fuel price crisis in 2022 highlighted the strategic economic value of renewable energy for energy security and affordability. Renewables provided a crucial buffer against skyrocketing fossil fuel prices, with renewable power sources deployed since 2000 saving an estimated USD 521 billion in global electricity fuel costs. This period marked one of the most substantial improvements in renewable power competitiveness seen in the last two decades.

2.3.4 Long-Term Cost Competitiveness of Renewables

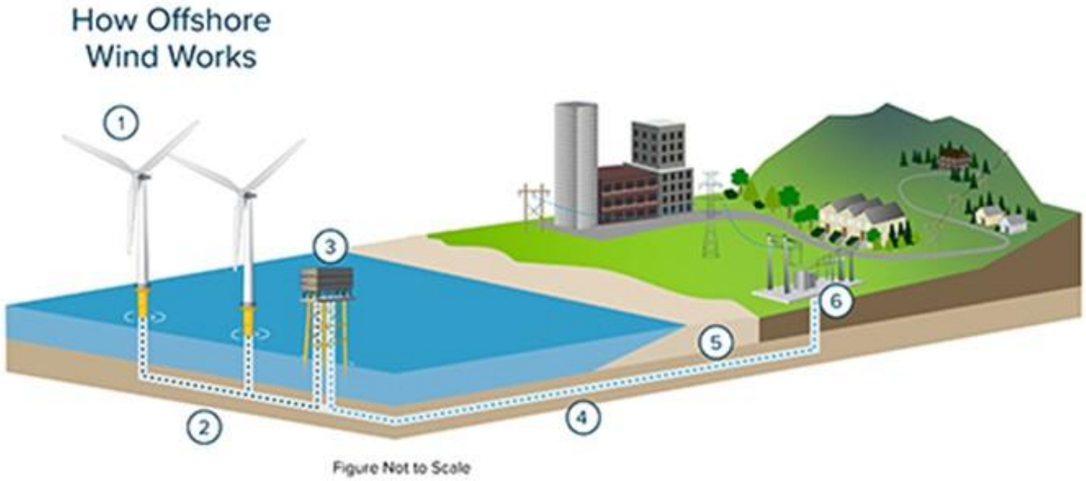
Looking at trends since 2010, the cost competitiveness of renewables has advanced dramatically:

- Onshore Wind: In 2010, onshore wind's global weighted-average LCOE was 95% higher than the most affordable fossil-fuel-fired power. By 2022, the cost of new onshore wind projects was 52% lower than fossil fuel-fired solutions, signaling a strong competitive position.
- Solar PV: Solar PV's cost reductions were even more pronounced. In 2010, solar PV was 710% more expensive than the lowest-cost fossil fuel option. Thanks to rapid improvements in efficiency and production scaling, by 2022, solar PV achieved a 29% cost advantage over fossil fuels.
- Offshore Wind's Future Potential: While currently more costly than other renewable sources, offshore wind remains poised for cost reductions through technological advancements, economies of scale, and streamlined regulatory frameworks. The potential for offshore wind to provide substantial renewable energy near densely populated coastal regions makes it a compelling investment for energy diversification, especially as the industry matures and costs begin to decline.

2.4 What are key components of Offshore Wind Turbines?

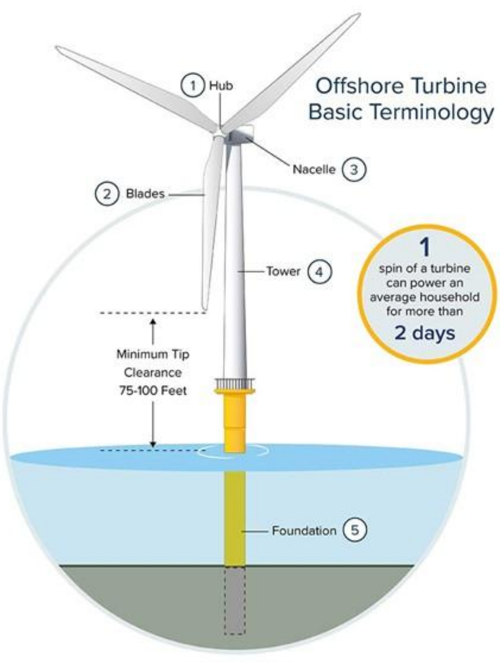
2.4.1 Power Generation Components of Off-Shore Wind Farm

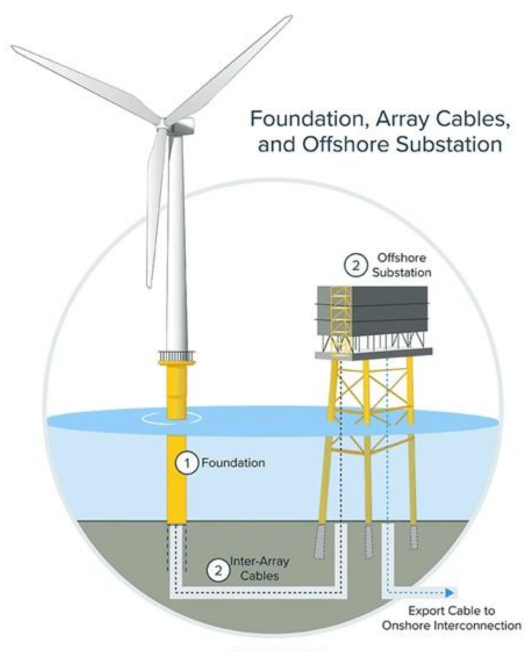
Offshore wind turbines are like giant fans that spin in the ocean breeze, capturing the energy from the wind and turning it into clean electricity. These turbines are anchored to the ocean floor with strong foundations, kind of like giant legs that keep them stable. As the turbines spin, they generate electricity that travels through underwater cables to a special station in the ocean called an offshore substation. From there, the electricity flows through a buried cable to another station on land, called an onshore substation. Finally, the electricity is fed into the power grid, which is like a network of power lines that supply electricity to homes, businesses, and communities. Offshore wind turbines harness the ocean's wind energy and convert it into renewable electricity that powers our lives.



2.4.2 Turbine Components of Off-Shore Wind Farm

A wind turbine is made up of four main parts that work together to turn wind energy into electricity. The hub is the central part that supports the long, curved blades, which capture the wind's energy and convert it into mechanical energy. The hub also houses a system that optimizes the blade angle and speed to get the most energy out of the wind. The mechanical energy is then sent to the nacelle, which is like a big housing that contains the components that convert the mechanical energy into electrical energy. Finally, the tower is the supporting structure that holds everything up, carrying the weight of the nacelle, hub, and blades.



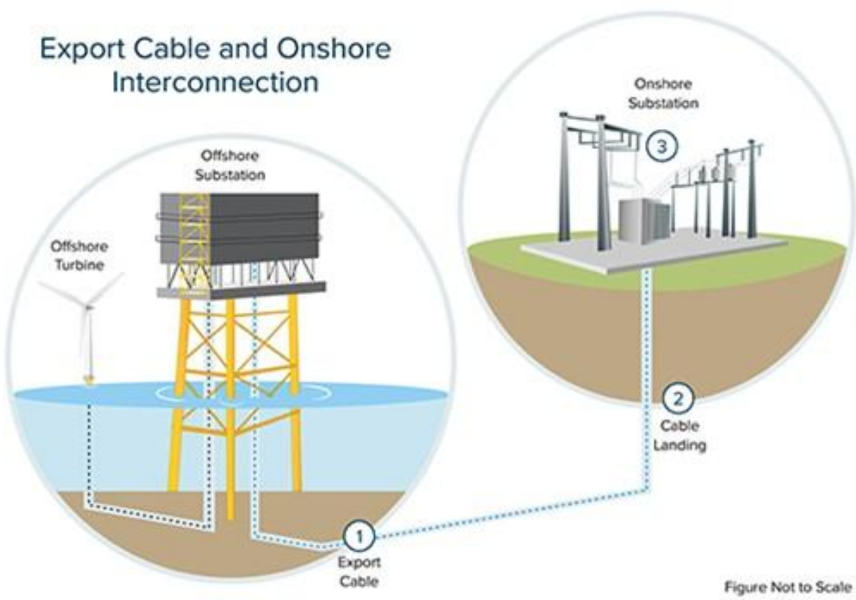


2.5 The Power Transmission Process of an offshore substation its Foundations, Array and Cables

Offshore wind turbines need a strong foundation to stand tall in the ocean, so they're secured to the sea floor using special structures like jackets or monopiles. These foundations keep the turbines stable and safe. Once the turbines generate electricity, it needs to be collected and sent to the shore. That's where array cables come in - they link the turbines together like a network of power highways, carrying electricity from each turbine to a central hub called the offshore substation. The offshore substation is like a power processing plant, where the electricity is collected, stabilized, and prepared for transmission to the shore. From there, it can power our homes, businesses, and communities.

2.6 Export Cable and Onshore Connection of Off-Shore Wind Farm

When the offshore wind turbines generate electricity, it needs to be transmitted to the land so we can use it. To do this, a special underground cable called the export cable carries the power from the offshore substation to the onshore substation. This cable is buried deep beneath the ocean floor to avoid disturbing marine life and ocean activities. Once it reaches the shore, the cable is carefully connected to the existing power grid through a process called horizontal direction drilling, which minimizes environmental impacts and disruption to beaches. Finally, the electricity is transferred to the existing transmission network, where it can power homes, businesses, and communities. In short, it’s just like an underground power highway that connects the offshore wind turbines to our onshore power grid.



3 Global Offshore Wind Outlook [14]:

Offshore wind energy is emerging as a key component of the global energy transition, because of its enormous potential and capacity to produce significant amounts of clean electricity. It has established itself as a mature, competitive, and scalable industry, significantly contributing to decarbonization efforts. Offshore wind provides large-scale, reliable power without competing for limited land space, making it an ideal solution for enhancing energy security and system resilience. The offshore wind industry is prepared to play a crucial part in reaching global renewable energy objectives and sustaining a 1.5°C trajectory, with a target of 380 GW of capacity by 2030.Furthermore, offshore wind generates jobs and sustainably grows the economy, offering significant economic advantages. Offshore wind is being used by nations like South Korea, the Philippines, and Brazil to boost local economies and meet domestic energy demands. It is crucial to have a robust and cooperative framework for growth that incorporates growing consumer demand, industrial decarbonization, and government obligations.

In 2023, 10.8 GW of new offshore wind capacity was added to the global grid. Over the last ten years, the offshore market has grown by an average of 27% per year, in total 75.2 GW of installations as of the end of year 2022, or 7.4% of the world's wind capacity. With 24% more new additions than the year before, 2023 ranks as the second-highest year in offshore wind history. With 6.3 GW added in 2023, China overtook Europe in terms of annual offshore wind developments for the sixth consecutive year. This puts China's total offshore wind installations at 38 GW, 3.7 GW (11%) more than those in Europe. The Chinese offshore wind sector entered the "grid parity" period for the second time last year. Denmark, the United Kingdom, Germany, and the Netherlands are the other four markets that comprise the top five, or 92 GWEC.

In 2022, Asia overtook Europe as the largest regional offshore wind market globally. More than 40 GW of offshore wind capacity was operational in this region by the end of 2023; of that, China accounted for 37.8 GW (92%) and Taiwan (China) for 2.1 GW, Vietnam (0.8 GW), Japan (0.2 GW), and South Korea (0.1 GW). By the end of 2023, the total offshore wind installations in Europe had surpassed 34 GW, accounting for 45% of all offshore installations worldwide. At the end of the previous year, 42 MW of offshore wind power was operational in North America, outside of Europe and Asia, all of the installations being located within US borders.

The offshore wind market is set to grow significantly, with a compound annual growth rate (CAGR) of 25% until 2028 and 15% up to the early 2030s. Annual installations are expected to triple by 2028, reaching 66 GW by 2033.Asia-Pacific, led by China, will dominate offshore wind installations, contributing 52% of global additions from 2024 to 2033. Europe will remain stable, driven by energy independence goals and climate commitments. Despite a promising outlook, the sector faces challenges such as inflation, increased capital costs, and supply chain constraints. These factors have led to a 10% downgrade in the near-term outlook (2024-2028). The inclusion

[14] https://gwec.net/wp-content/uploads/2024/06/GOWR-2024_digital_final_v2.pdf

of a global goal to triple renewable energy by 2030 in the COP28 text is historic. Governments and developers are committed to offshore wind, with significant investments and supportive policies expected to drive growth.

Table 1.New offshore wind installations and their total share in offshore wind market

Country	**New Installations (GW)**	**Market Share (%)**	**Total offshore wind installations share (%)**
China	6.3	58.4	50.3
Netherlands	1.9	17.8	6.3
United Kingdom	0.84	7.7	19.6
Taiwan (China)	0.69	6.4	3
France	0.36	3.3	1.1
Denmark	0.35	3.2	3.5
Germany	0.26	2.4	11.1
Japan	0.065	0.6	0.6
Norway	0.033	0.3	0.3
South Korea	0.004	0.04	0.04
Others	0.0022	0.02	5.1

3.1 Onshore Wind

With respect to onshore wind as well the global developments have been exponential. Onshore wind turbine technology has advanced significantly over the past decade. Larger and more reliable turbines, along with higher hub heights and larger rotor diameters, have combined to increase capacity factors. In addition to these technology improvements, total installed costs, operation and maintenance (O&M) costs, and LCOEs have been falling as a result of economies of scale, increased competitiveness and the growing maturity of the sector. In 2022, the extent of onshore wind deployment was second only to that of solar photovoltaic (PV), while China was still the largest market, albeit with a lower share than in 2020. The largest share of the total installed cost of an onshore wind project is related to the wind turbines, which today make up between 64% and 84% of the total cost (IRENA, 2018). Virtually all onshore wind turbines today are horizontal axis, predominantly using three blades and with the blades upwind. 27 Contracts for these projects typically include the towers, installation and, except in China, delivery. The other major cost categories include installation, grid connection and development costs. The latter includes environmental impact assessment and other planning requirement costs, project costs, and land costs, with these representing the smallest share of total installed cost[15].

15 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2023/Aug/IRENA_Renewable_power_generation_costs_in_2022.pdf

3.2 Targets by Countries for Offshore Wind Development [16]:

3.2.1 United Kingdom

In 2023, the United Kingdom (UK) connected 833 MW of offshore wind capacity, including 820 MW from the Seagreen project and 13 MW from the Dogger Bank project. The UK has a significant share of the global offshore wind market, with a total installed capacity of 19.6% of the global total. The UK aims to achieve 50 GW of offshore wind capacity by 2030. The Crown Estate has boosted the Celtic Sea floating wind leasing round to 4.5 GW and plans to unlock space for up to 12 GW of offshore wind capacity in the Celtic Sea. The UK government has increased the bid price ceilings under CfD AR6 to support the offshore wind industry, with a budget of GBP 800 million for the AR6 auction round. The UK's electricity system operator proposed a GBP 58 billion grid investment to incorporate an additional 21 GW of offshore wind into the grid by 2035.The UK offshore wind sector faced challenges due to low strike prices and rising costs, leading to no bids in the CfD AR5 auction. In response, the UK government has adjusted policies and increased financial support to ensure the continued growth of the offshore wind sector.

3.2.2 Europe

Europe can be considered as the birthplace of offshore wind technology. Despite losing its world-leading position in total installed offshore wind capacity to the Asia-Pacific region, Europe remains the largest market for floating wind farms and a technology hub for floating wind turbines and foundations. The EU's new energy security strategy, REPowerEU, is expected to accelerate offshore wind and renewable hydrogen deployment. The EU Wind Power Package and the European Wind Charter show a strong commitment to strengthening Europe's wind value chain. Annual installations are projected to surpass 10 GW by 2028 and 20 GW by 2030. Key initiatives include the AquaVentus project in the North Sea, aiming for 10 GW of green hydrogen generation capacity, and the NortH2 Project in the Netherlands, which plans to produce up to one million tonnes of green hydrogen annually by 2040. These projects highlight Europe's focus on integrating offshore wind with green hydrogen production to enhance energy security and economic stability[17].

[16] https://gwec.net/wp-content/uploads/2024/06/GOWR-2024_digital_final_v2.pdf
[17] https://gwec.net/wp-content/uploads/2024/06/GOWR-2024_digital_final_v2.pdf

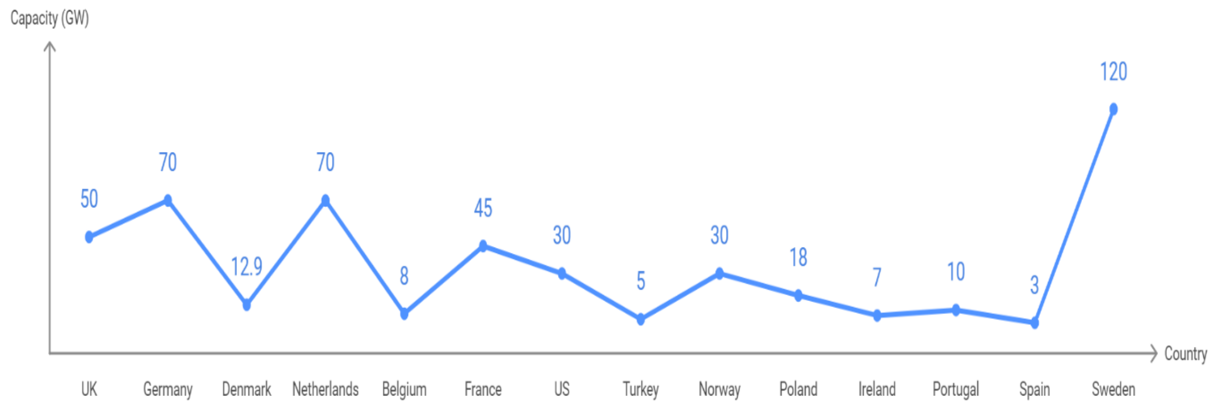


Figure 1. Offshore wind Targets (maximum capacity) in Europe

3.2.2.1 Germany:

Germany has been a significant player in offshore wind energy, with its first small projects totaling 836 MW connected in the past four years. The market faced slow growth due to unfavorable conditions and lack of mid-term visibility. The German Offshore Wind Energy Act (WindSeeG), amended in 2022, provides long-term visibility and sets ambitious targets: 30 GW by 2030, 40 GW by 2035, and at least 70 GW by 2045. The Act introduced two-track auction systems and negative bidding to stimulate growth. In 2023, Germany launched and awarded 8.8 GW of offshore wind capacity through a zero-subsidy tender. Entering 2024, Germany has launched tenders for 2.5 GW of non-centrally pre-surveyed capacity and 5.5 GW of centrally pre-surveyed capacity, all in the North Sea. Germany has signed cooperation agreements on offshore wind development and green hydrogen with North Sea and Baltic Sea countries. The Federal Maritime and Hydrographic Agency (BSH) released an offshore wind area development plan mapping out 36.5 GW of buildout by 2030. Despite the progress, BSH expects grid connection delays, impacting the capacity scheduled to be online by 2030. However, Germany's commitment to offshore wind and green hydrogen production, supported by robust legislative frameworks and international cooperation, positions it for significant growth in the coming years.

3.2.2.2 Denmark:

Denmark is the birthplace of offshore wind technology, hosting the world's first fixed-bottom offshore wind project in 1991 and the first MW-scale floating offshore wind project in 2009. It is also home to Vestas, the world's largest offshore wind turbine supplier, and the port of Esbjerg, the world's largest offshore wind port. In 2022, Denmark announced a plan to tender 9 GW of new offshore wind capacity. By April 2024, it launched its largest offshore wind tender with 6 GW of capacity across six sites, potentially increasing to 10 GW with an 'over-planting' option. The state will own a 20% stake in these projects. Denmark has been proactive in securing energy independence from Russian oil and gas. It hosted the Esbjerg and Marienborg declarations, involving multiple North and Baltic Sea countries, to enhance regional cooperation in offshore wind development. The government suspended the open-door scheme for offshore wind projects in February 2023 due to potential EU law breaches. While nine projects totalling 3.6 GW were allowed to continue, 24 out of 33 proposed projects were cancelled. The current targets in Denmark are for offshore wind to reach a cumulative installed capacity of 12.9GW in 2030[18].

3.2.2.3 Netherlands:

The Netherlands is the third-largest offshore wind market in Europe, with nearly 5 GW of offshore wind capacity in operation. To meet the EU's CO_2 emissions reduction target, the Netherlands has increased its 2030 offshore wind target from 11.5 GW to 22.2 GW. In June 2022, the Dutch government disclosed tendering timelines and locations for nine offshore wind projects with a combined capacity of up to 13.4 GW. These projects, individually ranging from 700 MW to 2 GW, are scheduled to be put out to tender between the second quarter of 2025 and the end of 2027.The Netherlands commissioned 1.9 GW of offshore wind capacity in 2023, replacing the UK as the region's largest market in terms of new additions. More than 170 units of SGRE's SG-11 DD offshore wind turbines were connected across the Hollandse Kust Noord (760 MW) and the Hollandse Kust Zuid 1-4 (1.5 GW) wind farms. The current targets in

Netherlands are for offshore wind to reach a cumulative installed capacity of 22.2GW in 2030, 50GW in 2040 and 70GW in 2050[19]. Plans are in place to reach that target, with Germany hoping to derive 80% of its power from clean sources by 2030.

3.2.2.4 Belgium:

Belgium remains Europe's fifth-largest offshore wind market with an operational capacity of 2.25 GW. Recent projects include the Seamade (487 MW) and Northwester 2 (219 MW) wind farms. The Council of Ministers approved increasing the capacity to be offered at upcoming tenders for the Princess Elisabeth offshore wind zone from 2.25 GW to up to 3.5 GW. This zone will be connected to an energy island, with construction expected to last until August 2026. The world's first artificial energy island is under construction, supported by an EU grant under the Recovery and Resilience Facility (RRF). This island will facilitate the connection of wind farms in the Princess Elisabeth zone. Belgium aims to quadruple its offshore wind capacity to 8 GW by 2040 to reinforce energy independence, reduce energy bills, and cut CO_2 emissions.

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[18] https://www.statista.com/statistics/1454986/offshore-wind-capacity-targets-europe/
[19] https://www.statista.com/statistics/1454986/offshore-wind-capacity-targets-europe/

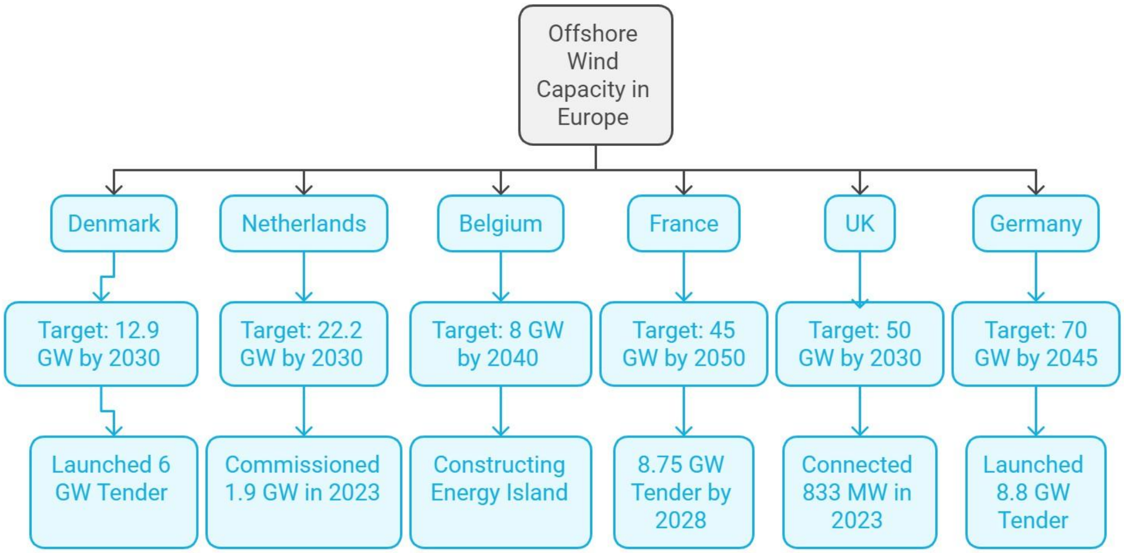


Figure 2. Offshore Wind Market Progress in Europe

3.2.2.5 France:

By the end of 2023, France had installed 842 MW of offshore wind capacity. Eight projects totalling 2.1 GW are under construction, including three demonstration floating wind projects. France aims to tender 8.75 GW of offshore wind capacity by 2028. The country plans to launch a 10 GW offshore wind auction before 2027 and has set a target of 45 GW by 2050, with an intermediate target of 18 GW by 2035.France's Energy Regulatory Commission (CRE) and the Ministry of Energy Transition are accelerating offshore wind development. Recent auctions include the 1 GW AO4 project and the 250 MW AO5 project, with more auctions planned for 2024 and beyond. The French government has signed an offshore sector deal with the wind industry to achieve these ambitious targets, emphasizing transparent auction designs, stable regulatory frameworks, and efficient permitting procedures.

3.2.2.6 Norway:

Norway is the largest floating offshore wind market with 100.5 MW in operation. The government plans to develop 30 GW of offshore wind capacity by 2040, with strategic impact assessments underway for 20 new areas.

3.2.2.7 Poland:

Poland had no offshore wind turbines by the end of 2023. The 1.1 GW Baltic Power project reached financial close, with construction expected to start soon. The country aims for 18 GW of offshore wind capacity by the end of the decade.

3.2.2.8 Ireland

Ireland has 25 MW of offshore wind in operation and aims for 7 GW by 2030. The government issued Maritime Area Consents for seven projects and awarded nearly 3,100 MW under ORESS 1. Future plans include 20 GW by 2040 and at least 37 GW by 2050.

3.2.2.9 Portugal:

Portugal has 25 MW of floating wind capacity. The government plans to auction 10 GW of offshore wind in phases, starting with 3.5 GW in 2023. The first tenders are located in Viana do Castelo, Leixões, and Figueira da Foz. Spain has 12 MW of offshore wind capacity, with a goal of reaching up to 3 GW of floating offshore wind by 2030. The Roadmap for the Development of Offshore Wind and Marine Energy guides this expansion.

3.2.2.10 Sweden:

Sweden has 202 MW of offshore wind capacity. The government set a target of 120 TWh of annual offshore wind generation and designated new areas to support this goal. Offshore wind energy production is prioritized over other uses.

3.2.3 United States:

By the end of 2023, the United States had 42 MW of offshore wind capacity in operation. However, four projects with a combined capacity of 4.3 GW are under construction, and there are another 50 GW of offshore wind projects in the development and planning stages. The US has set an ambitious target of 30 GW of offshore wind capacity by 2030. At the state level, eleven states have a combined offshore wind procurement target of 84 GW. The US offshore wind sector faced significant challenges in 2023, including inflation, increased capital costs, and supply chain constraints. These issues led to the termination of some offtake agreements and project developments. However, recent policy strides and regulatory changes aim to correct the course of the sector. The Biden administration supports offshore wind projects through tax incentives and supply chain loan programs. The Department of Energy has allocated $48 million for research and development to advance offshore wind technology and bolster domestic manufacturing capabilities. Additionally, several states have launched new offshore wind solicitations to boost development.

3.2.4 Turkey:

Turkey invited applications for the development of a 1.2 GW offshore wind project in 2018. However, this tender was postponed due to limited site preparation by the Ministry of Energy and Natural Resources (MENR). In June 2023, MENR launched a tender for site investigations and consultancy services for three development zones in the Sea of Marmara. This is expected to pave the way for Turkey's first offshore wind auction. Turkey aims to have 5 GW of offshore wind installations by 2035 under its National Energy Plan released in 2022. The country is focusing on overcoming site preparation challenges and leveraging its significant offshore wind potential to meet its ambitious targets.

3.2.5 Asia Pacific:

The APAC (Asia Pacific) region is the largest regional offshore wind power market today, accounting for 55% of global total installed offshore wind capacity by the end of 2023. This region is likely to make up 59% of the total capacity expected to be added worldwide between 2024 and 2030, bringing its total offshore wind power installations from 41 GW by 2023 to 172 GW by 2030. China is the largest offshore wind market today. Although offshore wind development targets have been released by the governments in Japan, South Korea, Taiwan (China), Vietnam, India, Philippines, and Australia, China will continue to dominate the growth in this region in the near term. With the offshore wind market becoming more diversified in APAC from 2028, however, this situation is likely to change and its market share in this region will drop to 69% in 2030 from 89% in 2023 as large commercial scale offshore wind projects will soon come online in South Korea and Japan and the first batch of offshore wind projects in emerging markets such as the Philippines, India, and Australia are expected to be built towards the end of this decade or early 2030s [13]. At present, the offshore wind supply chain development in this region is extremely uneven. According to the global wind supply chain report Mission Critical: Building the Global Wind Energy Supply Chain for a 1.5°C World, released by GWEC and BCG at COP28, only China has enough supply chain capacity to cope with the growth required to meet the Paris Agreement target. The rest of the markets in this region cannot even meet the 2030 offshore wind projection under the current business policy scenario. Excluding China, bottlenecks are likely to occur in this region for turbine nacelles (from 2026), blades (from 2025), towers (from 2024), castings (from 2025), foundations (2023), turbine installation vessels (from 2025), and ports (from 2023).

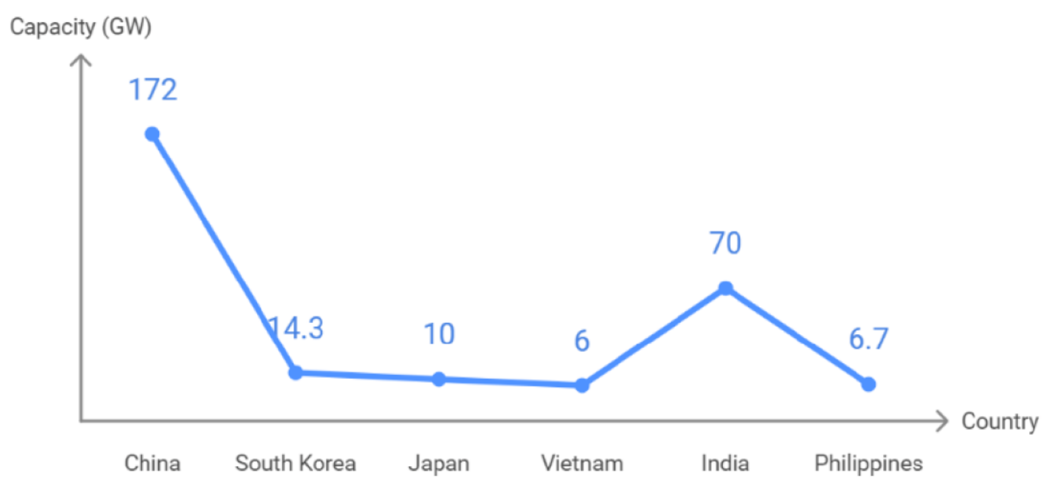


Figure 3. Offshore Wind Targets in APAC by 2030

3.2.5.1 China:

China commissioned its first commercial offshore wind project, the 102 MW Donghai Bridge offshore wind farm, in 2010. The market gained momentum with the introduction of the first offshore Feed-in-Tariff (FiT) scheme in 2014 and the Management Measures for Offshore Wind Power Development and Construction in 2016.By the end of 2015, China surpassed the 1 GW milestone in offshore wind installations. In 2018, China became the world's largest market for new offshore wind installations. By 2023, China added 6.3 GW of offshore wind capacity, bringing its total to 38 GW, which accounts for 50% of global cumulative offshore wind capacity. Chinese turbine OEMs have been launching larger turbines with greater power ratings. By 2023, the average offshore wind turbine size in China reached 9.7 MW. Companies like Manyang have introduced turbines in the 16–18 MW range, with the latest being a 22 MW model. China has developed a robust offshore wind supply chain, becoming the world's largest wind turbine manufacturing hub. The country accounts for 65% of global outputs of turbine nacelle and key components. The local supply chain has enabled cost reductions through scale. During the 14th Five-Year period (2021-2025), five large-scale offshore wind power bases (each with capacity around 10 GW) are to be developed in the Shandong Peninsula, the Yangtze River Delta region, South Fujian, East Guangdong, and Beibu Bay. The country aims to transition from nearshore to deep-water installations by the end of 2025, with a predicted addition of 160 GW of offshore wind capacity in the coming decade. So far, ten provinces have completed their offshore wind development plans, bringing the total offshore wind development target in China to 200 GW. The industry expects that the newly installed capacity for offshore wind will exceed 10 GW in 2024. GWEC Market Intelligence predicts that 72 GW of new offshore wind capacity will be added in China in 2024-2028, contributing 52% of the global offshore wind additions in this period.

3.2.5.2 South Korea:

South Korea has set an ambitious target of reaching 14.3 GW of offshore wind capacity by 2030. As of 2023, the country has 150 MW of installed capacity across seven wind farms. Offshore wind offers significant economic, social, and environmental benefits. It is expected to contribute significantly to the country's plan to achieve a 21.6% share of renewables in the power mix by 2030, as stated in its 10th Basic Plan for Electricity Supply and Demand. The permitting process in South Korea is complex and lengthy, involving around 20 permits before projects can enter the auction for a 20-year Fixed Price Contract. The Offshore Wind Power Promotion Act aims to streamline this process, but it requires bipartisan support and consensus from various stakeholders, including the Ministry of Fisheries and local communities. South Korea operates a Renewable Portfolio Standard (RPS) scheme, mandating large generators to produce a minimum proportion of their power with renewable energy. However, the current framework faces challenges, such as the variability of the Renewable Energy Certificate (REC) multiplier, which affects project bankability. Despite the challenges, South Korea has a strong project pipeline with over 19 GW worth of Electric Business Licenses (EBLs) granted.

3.2.5.3 Japan

As of the end of 2023, Japan has an installed offshore wind capacity of 153.5 MW, with 148.5 MW from fixed-bottom installations and 5 MW from floating wind installations. Japan aims to achieve 10 GW by 2030 and 30-45 GW by 2040.The most recent tender for a 356 MW wind farm off the coast of Happo-Noshiro in Akita prefecture was awarded in March 2024. The government is also working on reducing costs and establishing technology standards for floating offshore wind. A significant amendment to the Offshore Wind Promotion Act was made to allow for the development of offshore wind projects within Japan's Exclusive Economic Zone (EEZ). This change is expected to unlock larger-scale projects. Japan is focusing on streamlining regulations, fostering technological innovation, and prioritizing stakeholder engagement to achieve significant growth in offshore wind energy. The government has also set aside substantial funding to support large-scale floating demonstration projects.

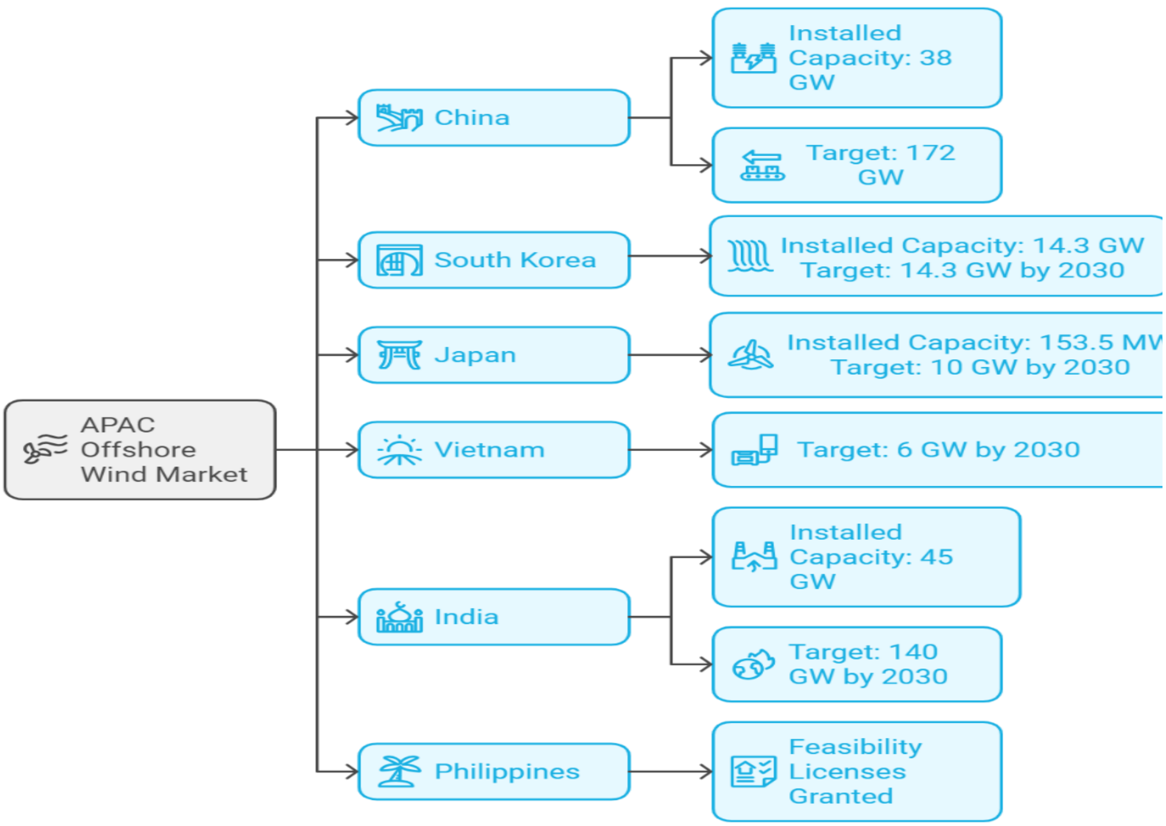


Figure 4. Offshore wind market Progress in APAC Region

3.2.5.4 Vietnam

Vietnam's national Power Development Plan 8 (PDP8) targets 6 GW of offshore wind installations by 2030, aiming to contribute approximately 4% to the total installed capacity. The government has published the first draft of a pilot mechanism for offshore wind in April 2024. This includes a streamlined permitting process, a robust Marine Spatial Planning (MSP) approach, and a clear timeline for auction implementation. Global Wind Energy Council (GWEC) has been actively engaging with industry stakeholders and the Vietnamese government, facilitating dialogue through taskforce and working group meetings. These efforts have been instrumental in advancing offshore wind development. Despite the ambitious targets, Vietnam faces challenges such as high financing costs and the need for a Route to Market process. Key components include implementing a simple remuneration mechanism for initial pilot projects and enhancing Power Purchase Agreement (PPA) bankability to attract international finance.

3.2.5.5 India:

India ranks fourth globally with over 45 GW of installed wind capacity. By 2030, India plans to achieve a cumulative 140 GW installed wind energy capacity. India also holds significant potential for offshore wind energy. The Ministry of New and Renewable Energy (MNRE) aims to harness an estimated 70 GW of offshore wind energy capacity off the coasts of Gujarat and Tamil Nadu by 2030.The National Offshore Wind Energy Policy, notified in 2015, lays the groundwork for the strategic development of offshore wind projects. In early 2024, the Solar Energy Corporation of India (SECI) announced a “Request for Selection” for 4 GW of seabed lease off the coast of Tamil Nadu. Offshore wind projects are expected to generate substantial economic activity, including job creation during various project phases and the development of supporting industries such as vessel manufacturing and maintenance services. Offshore wind projects demand significant initial investments and involve lengthy project timelines. To facilitate this, the central government has planned a 10 GW grid infrastructure for offshore wind projects and approved viability gap funding (VGF) for an initial 1 GW of capacity, with additional support measures like an ISTS waiver until 2032.

3.2.5.6 Philippines:

The Philippines has been exploring its offshore wind potential since 2020. In 2022, the Department of Energy (DOE) launched the country’s first offshore wind roadmap. The Marcos administration removed foreign ownership restrictions, enabling 100% foreign-owned companies to invest in the renewable energy sector. By April 2024, the DOE awarded ninety-two offshore wind energy service contracts with a potential capacity of 65 GW. The President issued an executive order directing the DOE to develop a policy and administrative framework to support offshore wind development and commence grid development work. The DOE aims to have at least ten offshore wind projects with a combined capacity of 6.7 GW generating power by 2028. However, achieving this target will be challenging. The DOE is ensuring an aligned transmission development plan and conducting an offshore wind supply chain study to outline the baseline capabilities of the Philippines.

3.2.6 Australia:

The Australian offshore wind sector continues to progress at a rapid rate. On May 1, 2024, the Australian Government granted the first set of feasibility licences for offshore wind projects off the coast of Gippsland in Victoria to six projects. These include High Sea Wind, Gippsland Skies, Blue Mackerel North, Kut-Wut Brataualung, Ørsted Offshore Australia 1, and Star of the South

Wind Farm. Additionally, six more licences will be granted soon. The licence area has the potential to bring 25 GW of offshore wind into Victoria's energy mix if all twelve projects are built. This follows at least six years of collaboration between the industry and the federal government. The Victorian Government released the Offshore Wind Energy Implementation Statements in March 2023 to guide the development of transmission infrastructure.

3.2.7 Saudi Arabia:

Saudi Arabia has an overall offshore capacity of 106 GW along its eastern and western coasts. The country aims to generate half of its energy from renewable sources by 2040 and reach net zero by 2060.The Dumat al Jandal onshore wind farm is currently operational, with future plans for offshore wind development.

3.2.8 Colombia

Colombia's electricity system is predominantly hydro-based, making it vulnerable to weather variability, particularly El Niño events. The country aims to diversify its energy mix to enhance resilience and accelerate decarbonization. Beyond its excellent onshore wind resources, Colombia has an offshore wind technical potential of 109 GW, according to the World Bank Offshore Wind Development Program, comprising 31 GW of fixed wind potential and 78 GW of floating potential. Most of the best offshore wind resources are located in the Caribbean Sea in the Northern extremes of the country, particularly off La Guajira's coast, where some areas have annual average wind speeds exceeding 10 m/s. The government has established a robust process for offshore wind development, including a competitive tender process for seabed allocation. Resolution 40284 of August 2022 sets the rules for this process. There are 11 projects with over 5 GW already registered. The first competitive tender process was launched in December 2023, targeting approximately 12,000 km² of seabed for projects over 200 MW.

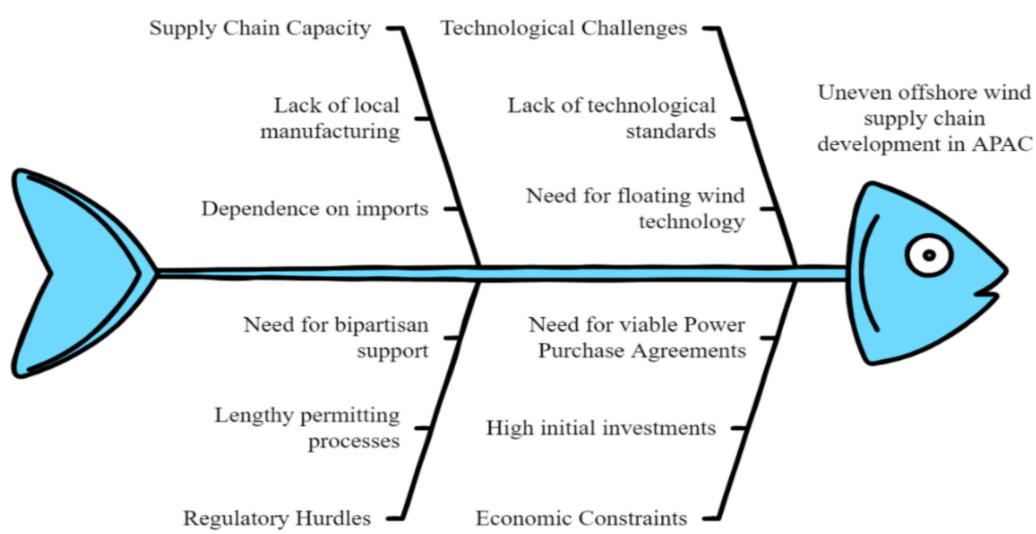


Figure 5. Challenges in APAC Offshore Wind Supply Chain Development

3.2.9 Brazil

Brazil views offshore wind as a future clean power source for its heavy industry. The government is actively embracing offshore wind to meet its sustainable economic development goals. Brazil has faced delays in offshore wind legislation due to political challenges. However, the government is now working to build out regulations to ensure an investable sector. Offshore wind is seen as a significant opportunity for green industrialization in Brazil. The development of offshore wind projects is expected to generate substantial economic activity, including job creation and local economic growth. Brazil has encountered opposition from local communities, particularly fishing communities, concerned about the impact on marine life and fishing industries. Efforts are being made to engage with these communities and address their concerns through transparent and inclusive processes.

3.2.10 South Africa:

South Africa's wind energy market has matured significantly over the past decade, largely due to the inclusion of wind in the country's energy planning. The Integrated Resource Plan (IRP) of 2010 paved the way for utility-scale wind projects, with the first wind farms reaching commercial operation in 2014.As of now, South Africa has completed 34 wind farms with a total output of 3,442 MW. This steady growth has positioned South Africa as a prime onshore investment destination in the region. South Africa has an annual offshore wind energy production potential of 44.52 TWh in shallow waters and 2,387.08 TWh in deeper waters. Despite the vast potential, the development of offshore wind in South Africa faces significant challenges, including high costs and an unclear permitting regulatory framework. The World Bank has begun studies to create an Offshore Wind Roadmap for South Africa, expected to launch later in 2024. This roadmap aims to address these challenges and unlock the country's offshore wind potential.

3.2.11 Morocco:

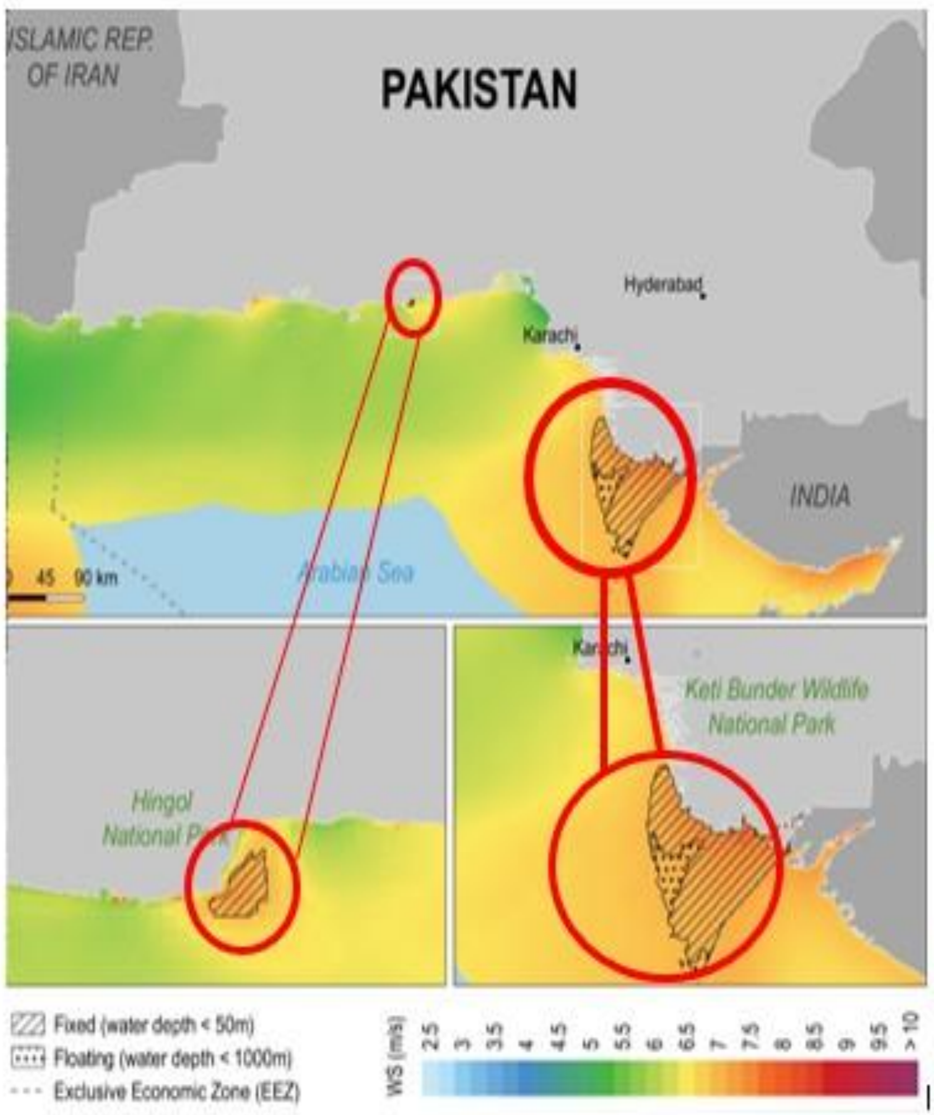
Morocco relies heavily on energy imports, with over 91% of its energy coming from external sources. The government aims to reach 51% renewable energy by 2030.The European Investment Bank (EIB) awarded a $2 billion grant to the Moroccan Agency for Sustainable Energy (MASEN) to conduct a feasibility study for offshore wind. Morocco's offshore wind potential is estimated at around 200 GW.

4 Can Pakistan Explore Offshore Wind?

4.1 Pakistan's Offshore Wind Potential

The map below shows the areas in Pakistan's ocean where wind energy can be harnessed to generate electricity. The map displays the potential for both fixed and floating offshore wind farms within 200 kilometers of the shoreline. Fixed wind farms are suitable for shallow waters (less than 50 meters deep), while floating wind farms can be installed in deeper waters (up to 1000 meters deep). The colors on the map indicate the strength of the wind resource, with darker colors showing higher wind speeds.

Map of Pakistan's offshore wind potential



Courtesy – ESMAP & World Bank – Technical Potential of Offshore Wind in Pakistan

The map also shows the Exclusive Economic Zone (EEZ), which is the area where Pakistan has rights to explore and use marine resources. The country's exclusive economic zone (EEZ) spans 290,000 km², providing vast space for offshore wind farms. Offshore wind speeds average 8-10 m/s, further enhancing Pakistan's offshore wind potential. The World Bank and ESMAP (Energy Sector Management Assistance Program) have developed this map as part of an initiative to promote offshore wind energy. The map estimates that Pakistan has a total technical potential of 21 gigawatts (GW) for offshore wind energy, which can help power homes, businesses, and industries. Pakistan's offshore wind potential is substantial, with estimates suggesting 150 GW of capacity.

4.2 Does any discourse exist already on offshore wind?

A nascent discourse on offshore wind energy exists in Pakistan, driven by the country's growing focus on renewable energy sources. Although still in its infancy, the discussion encompasses various aspects, including the country's total technical offshore wind energy potential of 21 GW. Pakistan has a vast coastline along the Arabian Sea, offering significant potential for harnessing offshore wind energy.

Research studies have demonstrated that Pakistan's offshore wind resources are substantial, particularly off the coasts of Sindh and Balochistan. By leveraging offshore wind energy, Pakistan can address its energy crisis by increasing power generation, reducing transmission losses, and improving grid resilience, while also mitigating climate change impacts. Assessments of wind speeds, directions, and turbine installation feasibility have been conducted, highlighting the potential for offshore wind farms to achieve a capacity factor of 45-50%, compared to 25-30% for solar PV. This ensures a more stable power supply.

Offshore wind farms can be connected to the grid via high-voltage direct current (HVDC) transmission, minimizing losses and ensuring efficient power transfer. Moreover, offshore wind turbines can generate up to 12 MW each, compared to 2-3 MW for onshore turbines, resulting in higher power output. This can improve the load factor of Pakistan's power system, reducing the strain on existing infrastructure and minimizing the need for peaking power plants.

While the government has expressed interest in exploring all forms of renewable energy potential, the on-shore wind potential is yet to be fully utilized. However, replacing fossil fuels with offshore wind energy can save Pakistan up to 3.5 million tons of fuel annually, equivalent to approximately $1.5 billion. Nevertheless, Pakistan's electricity regulatory authorities face challenges in curtailment and operations & maintenance.

Furthermore, adopting offshore wind energy poses several challenges, including technological and infrastructure limitations, high costs, and environmental concerns. Geostrategic, technical, power infrastructure, technological, and trade route challenges also need to be addressed. Although concrete plans and policies for offshore wind development are still in the early stages, recognizing these challenges is crucial for harnessing Pakistan's offshore wind energy potential.

4.3 Is generation planning considering the importance of wind energy?

The latest Integrated Generation Capacity Expansion Plan (IGCEP) for 2024-2034 reveals a plan to further harness wind energy, with a target of 1,942 MW of wind power capacity planned for commissioning by 2034. This is a positive step towards recognizing the importance of wind energy in Pakistan's energy mix.

However, the sector faces challenges, including curtailment, which led to an 11% decrease in wind energy generation in FY 2022-23. Excessive curtailment has left wind power projects struggling to fulfill debt obligations and sustain viability. Proposed measures, such as potential reductions in net metering buyback rates and high Use of System Charges in the CTBCM, paint a bleak picture for the sector.

Despite these challenges, wind energy is crucial in meeting future renewable energy targets, as its generation profile matches Pakistan's demand profile, especially during evening peaks and at night. Wind energy can help address the country's energy crisis by reducing reliance on imported fossil fuels and mitigating climate change impacts.

However, the latest IGCEP 2024-34 iteration does not consider the importance of wind energy, slashing the share of cost-effective variable renewable energy, including wind energy, in the energy mix from nearly 18% to 0.5%. This move goes against Pakistan's National Electricity Policy 2021 and Alternate and Renewable Energy Policy 2019 targets.

In IGCEP 2024-33 the VRE share has been reduced to 13.3% in the energy mix from the previously projected 29.6% in IGCEP (2022-31). The solar share, including net metering, is projected to drop to 10% by 2034. This move not only goes against policy targets but also breaches the principle of the least cost to hold down consumer electricity tariffs.

The World Bank's “Variable Renewable Energy Integration and Planning Study” estimates the theoretical potential for wind generation in Pakistan at 340GW, mainly in Sindh and Balochistan. However, the new IGCEP (2024) plan overlooks the renewable energy potential in Sindh and Balochistan, which threatens to undermine the regions' economic development and the nation's commitment to renewable energy targets.

A re-evaluation of the IGCEP is essential to harness the full potential of Pakistan's renewable resources and ensure a balanced and inclusive approach to energy and economic development. The generation planning should consider the importance of wind energy and other cost-effective renewable sources to ensure a sustainable and inclusive energy mix.

4.4 How has onshore wind been treated in Pakistan? Has it met with resistance or bottlenecks?

Pakistan has been actively pursuing onshore wind energy as a renewable energy source to address its energy crisis. Despite its potential, onshore wind energy development in Pakistan faces several challenges and limitations. The country is blessed with abundant wind resources, particularly in the southern and western regions, and has identified several wind energy corridors with high wind speeds.

However, the development of onshore wind energy has been hindered by high upfront costs, which are a significant barrier for a country already facing an energy crisis and poverty. Pakistan's onshore wind capacity accounted for 9.5% of total power plant installations globally in 2021, with a total recorded onshore wind capacity of 774GW. This is expected to contribute 13.1% by the end of 2030, with a capacity of installations aggregating up to 1,618GW.

4.5 Challenges in Wind Energy Development

Moreover, the wind potential is limited due to geographical diversity, with most existing wind projects located in Sindh and Balochistan. The majority of these projects are owned by private companies and foreign investors. The variable power production of wind energy also poses challenges for transmission infrastructure, and the limitation of new transmission lines and connections from future wind farms has been a significant bottleneck. Of the total global onshore wind capacity, 0.18% is in Pakistan.

4.5.1 Wind Power Transmission & Distribution Issues

The National Power Construction Corporation (NPCC) and National Transmission and Dispatch Company (NTDC) are facing challenges in integrating onshore wind power plants into the national grid. The main issue is inaccurate demand forecasting, which leads to penalties and additional costs. The existing grid isn't compliant with wind power grid codes, causing curtailment issues and inability to integrate batteries for power balancing. Moreover, NPCC and NTDC officials report faults and losses due to wind power generation. To address these issues, experts suggest using tools that enhance demand forecasting accuracy. However, power experts are hesitant to integrate more wind energy due to installation, operational, and utility issues, as well as concerns about reactive power decrease and national grid issues.

The Load Dispatch System Upgrade Project, executed by the National Transmission & Dispatch Company, aimed to modernize and upgrade the load dispatch center at the National Power Control

Center (NPCC) in Islamabad. The project's objective was to convert the current analog system to a digital system, including components like Digital Processing System, Supervisory Control & Data Acquisition, Energy Management System, and Remote Terminal Units. The project also included the installation of optical fiber ground wire and equipment for regional control centers. The project's goal was to ensure efficient and reliable power transmission and distribution throughout Pakistan.

Despite these efforts, the integration of onshore wind power plants into the national grid remains a challenge. The NPCC and NTDC face difficulties in balancing power generation according to merit order-based power generation and allotted energy demand. The inaccuracy in demand forecasting leads to penalties and additional costs for the NPCC and NTDC. The existing grid's non-compliance with wind power grid codes further exacerbates the issue, causing curtailment issues and the inability to integrate batteries for power balancing.

To address these challenges, it is essential to enhance the accuracy of demand forecasting and upgrade the existing grid infrastructure to comply with wind power grid codes. Additionally, the NPCC and NTDC must work together to resolve the issues related to faults and losses due to wind power generation. The integration of onshore wind power plants into the national grid is crucial for Pakistan's energy sector, and addressing these challenges is critical for a sustainable energy future.

4.5.2 Policy and Regulatory Framework

Furthermore, Pakistan's policy and regulatory framework for wind energy is still evolving and can be inconsistent, creating uncertainty for investors. The current policy requires the National Electric Power Regulatory Authority (NEPRA) to buy 100% of the power from wind power plant developers at a fixed tariff, which encourages investment but does not incentivize developers to explore cost-effective processes and technologies.

4.5.3 Infrastructure and Integration Challenges

Moreover, wind projects require suitable infrastructure, including roads, transmission lines, and substations, which can be lacking in some areas. The integration of wind power into the existing grid has also been a challenge due to the aged and weak infrastructure, resulting in curtailment issues and penalties for power plants and grid operators.

4.5.4 Land Acquisition and Community Issues

Land acquisition issues have also been a significant challenge, with companies facing difficulties due to government and local resistance, land ownership disputes, agricultural use, or environmental concerns. Technical challenges such as dust and humidity have affected turbine performance and maintenance, and local communities have raised concerns about noise and visual impact.

4.5.5 Recommendations and Future Outlook

To address the challenges, experts recommend better risk management techniques, the use of indices to understand wind power intermittence, and improved scheduling with existing hydro and thermal power stations. The integration of more wind energy into the national grid and energy mix of Pakistan has been met with reluctance due to installation, operational, and utility issues.

4.6 Case Studies of Wind Power Projects

Several onshore wind power projects, including the 147.90MW Triconboston Wind Power Project, 99MW UEP Wind Farm, 60MW Jhimpir-Metro Wind Power, 56.40MW Zorlu-Jhampir Power Project, and 52.80MW Jhimpir- Sapphire Wind Power Company, have faced challenges such as land acquisition difficulties, transmission infrastructure constraints, grid connectivity issues, technical difficulties with turbine installation, and community displacement issues.

4.7 Industry Perspectives and Challenges

Companies owning wind power plants in Gharo, Dhani, Nooriabad, and Hub Pakistan have reported grid connectivity issues, transmission losses, limited transmission capacity, grid stability concerns, power evacuation challenges, and limited support from the government and other stakeholders. All wind power plants in Pakistan have faced challenges due to the evolving policy and regulatory framework, uncertainty about renewable energy targets and policies, and reduction in RE targets in generation and transmission planning.

5 Potential Challenges of Offshore Wind Development in Pakistan:

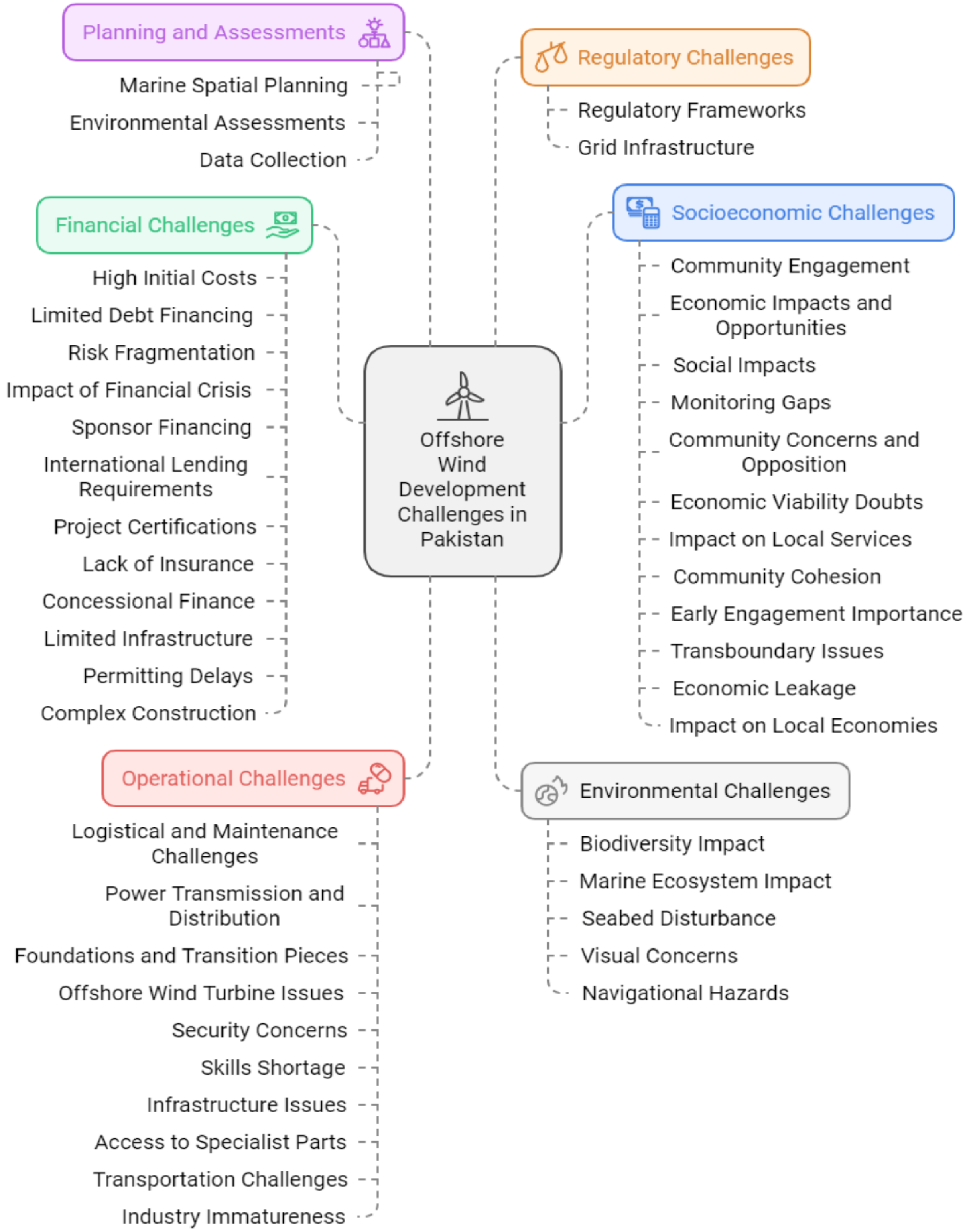


Figure 1. Challenges in the offshore wind development

5.1 Operational challenges:

Offshore wind energy development in Pakistan faces several operational challenges. The intermittency of wind energy requires high operational costs and proper transmission infrastructure.

5.1.1 Logistical and Maintenance Challenges:

Logistical challenges include transportation of personnel and equipment to offshore wind turbines, which is costly and complex. Regular monitoring and inspection of offshore wind turbines are essential to ensure safe and efficient operation.

5.1.2 Challenges in Power Transmission and Distribution:

Technical losses in the transmission and distribution system, as well as electricity theft, are significant contributors to power shedding in Pakistan. The intermittent nature of wind energy necessitates the development of energy storage solutions to ensure a stable power supply when the wind is not blowing.

5.1.3 Foundations and Transition Piece Challenges:

Offshore wind development faces several challenges related to foundations and transition pieces, including internal and external corrosion due to the aggressive marine environment. High-throughput fabrication and advanced manufacturing methods are required to address these issues.

5.1.4 Offshore Wind Turbine Challenges:

The Offshore wind turbines are exposed to harsh ocean environments, making maintenance and operation challenging. Maintenance activities are limited by weather conditions, and wind turbines can only be installed in areas with suitable wind speeds, which may limit their geographical distribution.

5.1.5 Security Concerns:

The Offshore wind potential locations of Pakistan are close to the Indian and Iran border, which raises security concerns. Protection of infrastructure and personnel from piracy and terrorism is essential.

5.1.6 Skills Shortage:

There is a limited number of specialists in offshore wind, making it challenging to meet decarbonization targets. Developers often work with consultants to access specialist knowledge, but there is a need for specialized training and capacity building.

5.1.7 Infrastructure Challenges:

Offshore wind farms require significant infrastructure, including substations, undersea cables, and transmission lines, which can be expensive and difficult to build. Remoteness of locations poses logistical challenges for construction and maintenance.

5.1.8 Access to Specialist Parts and Materials:

There is a lack of capacity for infrastructure and construction materials and equipment required for offshore wind farms. Significant investment is needed from project developers and government support.

5.1.9 Transportation Challenges:

Transporting turbines by specialist vessels can be challenging, especially for floating wind farms. Weather and sea conditions limit the use of tugboats, and alternative solutions are needed.

5.1.10 Industry Immatureness

The offshore wind industry faces challenges related to distance, water depth, weather windows, and policy issues. Increased O&M costs are due to predefined rules, lack of coordinated planning, and lack of a common approach to O&M management.

5.2 Financial Challenges:

Offshore wind is a highly capital-intensive industry requiring significant participation from the banking sector and the capital markets. The offshore wind industry has a strong record over the past decade, and financiers have grown increasingly comfortable with technology. Since 2010, US$68 billion66 has been deployed to finance offshore wind in the UK and US$37 billion in Germany. Despite the COVID-19 pandemic, 7.1 GW of new capacity was financed in 2020, raising US$32 billion, including for 1.5 GW Hollandse Kust Zuid (1–4) and 2.4 GW Dogger Bank A and B. Both balance sheet financing and limited recourse project financing have been used for offshore wind. Green bonds were issued by Ørsted in 2020 for a project in Taiwan and by Iberdrola in 2021 for projects in Germany and France. Most projects have used limited recourse project financing, demonstrating the degree of maturity and confidence built by the industry and financiers. Typically, international debt is cheaper than local debt and hence will help lead to lower LCOE. Attracting experienced international developers that brings the experience of project financing, and the confidence of international lenders, is important for emerging markets. Governments need to consider how policy decisions affect access to liquidity while managing the risk exposure to the public sector. Due to the large capital requirements and the complexity of offshore wind financing, projects carry significant development, construction, and operational risks. Financing ever larger projects has challenges, even in established markets. In addition, there are other risk factors to financing, such as rapid technical innovation to deploy larger turbines farther from the shore and in deeper water, or the phasing out of revenue support in certain markets. However, developing countries face challenges in securing the international finance support [20].

5.2.1 High Initial Costs:

Offshore wind turbines require significant investment due to the need for robust structures to withstand harsh marine conditions[21]. Offshore wind farms are significantly more expensive to construct, operate, and maintain compared to onshore installations. "Marinizing" turbines to withstand offshore conditions can add up to 20% to unit costs. Specialized foundations for offshore turbines can account for up to 30% of total turbine costs, compared to about 7% for onshore units. Connecting offshore wind farms to onshore electricity networks can account for 17-34% of the total cost, whereas for onshore wind farms, it's only about 5%. The harsh marine environment increases maintenance costs and delays, further adding to the expense Offshore wind costs approximately £2,300 per MW installed, compared to £1,300 per MW for onshore wind[16].

5.2.2 Limited Debt Financing:

The fragmented nature of risks and the involvement of multiple parties in offshore wind projects limit the availability of outside debt financing. Offshore wind projects typically involve separate contracts for different stages, such as development, construction, and operation, each with its own set of risks. This fragmentation increases the overall project risk, making lenders hesitant to provide debt financing. Additionally, the complexity of coordinating multiple contracts and managing the associated risks further complicates the financing process. As a result, debt financing for offshore wind projects is often limited, with lenders requiring higher returns to compensate for the increased risk. The fragmented nature of risks and parties involved in offshore wind projects limits the availability of outside debt financing[22].

5.2.3 Risk Fragmentation:

Offshore wind projects involve separate contracts for different stages, such as turbine supply, installation, and maintenance, which increases project risk and makes lenders hesitant to provide debt financing. Each stage of the project has its own set of risks, including technical, operational, and financial risks. For example, delays in turbine installation can lead to increased costs and project timelines, impacting the overall financial viability of the project. This fragmentation of risks requires meticulous risk management and coordination among various stakeholders to ensure

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[20] https://documents1.worldbank.org/curated/en/343861632842395836/pdf/Key-Factors-for-Successful-Dev elopment-of-Offshore-Wind-in-Emerging-Markets.pdf

[21] https://documents1.worldbank.org/curated/en/343861632842395836/pdf/Key-Factors-for-Successful-Dev elopment-of-Offshore-Wind-in-Emerging-Markets.pdf [16] https://core.ac.uk/download/pdf/56705704.pdf

[22] https://core.ac.uk/download/pdf/56705704.pdf

successful project execution. Lenders, therefore, demand higher risk premiums or may altogether avoid financing such projects due to the perceived complexity and risk. Offshore wind projects involve separate contracts for different stages, increasing project risk and making lenders hesitant to provide debt financing[23].

5.2.4 Impact of Financial Crisis:

The global financial and credit crisis has further discouraged major lenders and financial institutions from financing offshore wind projects. The financial crisis led to tighter credit conditions and increased scrutiny of large-scale infrastructure projects. As a result, many financial institutions became more risk-averse, reducing their exposure to high-risk sectors like offshore wind. The increased cost of capital and reduced availability of debt financing have made it challenging for developers to secure the necessary funds for offshore wind projects. This has led to a greater reliance on equity financing from large sponsors and government support to bridge the financing gap.

5.2.5 Sponsor Financing:

Due to high capital costs and operational challenges, offshore wind projects are typically financed by large, creditworthy sponsors, mainly utility companies[24]. These sponsors have the financial strength and stability to support the significant upfront investments required for such projects. For instance, companies like Ørsted, Equinor, and Iberdrola are prominent players in the offshore wind sector, leveraging their robust balance sheets to fund these capital-intensive projects. The involvement of these large sponsors not only ensures the availability of necessary funds but also instills confidence among other stakeholders, including contractors and suppliers.

5.2.6 International Lending Requirements:

The relatively higher risks and CAPEX of offshore wind will usually require a project finance structure supported by international lenders with stringent requirements, thus increasing the need for offtake agreements that adhere to international standards of bankability. To obtain financing from international lenders, projects need to meet Good International Industry Practice (GIIP) standards such as International Finance Corporation (IFC) PS6 and World Bank ESS6, which include specific environmental and social requirements. If national permitting requirements are not aligned with international lender requirements, this can delay or even preclude permitted projects from proceeding. For example, IFC PS6 requires that projects must achieve no net loss of natural habitats and a net gain of critical habitats. Aligning with GIIP standards allows developers to understand the most important issues to address in ESIA and gives a useful early indication of the scale of mitigation requirements of a project. Ensuring that projects are bankable, delivering

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[23] https://core.ac.uk/download/pdf/56705704.pdf
[24] https://core.ac.uk/download/pdf/56705704.pdf

ESIA will help projects to secure financing from multilateral institutions, which usually can only be accessed when the IFC PS, or equivalent, has been satisfied [25].

5.2.7 Project Certifications:

Project finance often requires third-party project certification against IEC standards. This increases assurance that the offshore wind project has been designed and implemented considering the conditions relevant to a specific offshore wind farm project, and following good practice captured in the standards[26].

5.2.8 Lack of Insurance:

Governments should consider how to create a regime that gives investors access to insurance from the international insurance and reinsurance markets. In Taiwan, the international reinsurance market was able to extend insurance capacity to this new geography, in collaboration with the local insurance market. Governments must also work to evolve their own regulations and insurance risk bearing capacities to develop the local insurance sector in a way that meets the needs of equity investors and lenders. For some uninsurable events, such as failure of an export cable or transformer, it is not possible to push all risks to investors as this can make projects unviable. Local risk factors can be addressed better through the collaboration of local and international insurance sectors. Offshore wind insurance will be influenced by local factors in emerging markets. Enhanced natural catastrophe and political or exchange rate risk will affect pricing or capacity available from international insurance markets.

5.2.9 Concessional Finance:

Concessional finance refers to financial resources or instruments provided on terms or conditions that are more favorable than those typically available in the market. Leveraging concessional finance to lower the initial cost premium offers a significant opportunity to help emerging market governments invest in offshore wind, thereby accelerating global decarbonization efforts[27].Effective deployment of concessional finance requires coordination among multiple stakeholders, including governments, MDBs, private sector developers, and financiers. Concessional finance can significantly reduce the financial barriers to offshore wind development, making it a more attractive and feasible option for emerging markets. This, in turn, supports global efforts to reduce greenhouse gas emissions and combat climate change.

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[25] https://documents1.worldbank.org/curated/en/343861632842395836/pdf/Key-Factors-for-Successful-De velopment-of-Offshore-Wind-in-Emerging-Markets.pdf

[26] https://documents1.worldbank.org/curated/en/343861632842395836/pdf/Key-Factors-for-Successful-De velopment-of-Offshore-Wind-in-Emerging-Markets.pdf

[27] https://core.ac.uk/download/pdf/56705704.pdf

5.2.10 Limited Infrastructure

Pakistan currently lacks the necessary infrastructure and logistical support for large-scale offshore wind projects, making implementation more complex [28].

5.2.11 Permitting Delays

Lengthy permitting processes increase risk and capital expenditure for developers, slowing down project timelines and potentially making projects outdated before completion[29].

5.2.12 Complex Construction

Offshore wind construction is more complex and time-consuming compared to onshore projects, involving longer development timelines and higher risks [30].

[28] https://gwec.net/wp-content/uploads/2023/08/GWEC-Global-Offshore-Wind-Report-2023.pdf
[29] https://gwec.net/wp-content/uploads/2024/06/GOWR-2024_digital_final_v2.pdf
[30] https://documents1.worldbank.org/curated/pt/716891572457609829/pdf/Going-Global-Expanding-Offshore-Wind-To-Emerging-Markets.pdf

5.3 Socioeconomic Challenges

Offshore Wind Farms (OWFs) are significant renewable energy projects that require extensive planning and assessment, particularly concerning their socio-economic impacts. These impacts encompass a wide range of issues affecting local and regional communities, including employment, economic benefits, and social well-being.

5.3.1 Community Engagement

Effective engagement with local communities is crucial to address concerns and gain support, ensuring that projects proceed smoothly and benefit local economies. Engaging with local communities from the earliest stages of OWF projects is essential to gain a "social licence to operate." This involves transparent communication, participatory approaches, and continuous dialogue with stakeholders. Developers should appoint Local Community Liaison Officers (LCLOs) to facilitate engagement, organize community workshops, and provide regular updates on project developments. Community Benefits Agreements (CBAs) are also recommended to ensure that local communities receive tangible benefits from OWF projects. These agreements can include funding for local services, education and skills training programs, and initiatives to support community cohesion. Monitoring and adaptive management throughout the project lifecycle help address community concerns and enhance the overall social acceptance of OWFs [31].

5.3.2 Economic Impacts and Opportunities

OWFs generate significant employment opportunities across various stages of their lifecycle, including development, construction, and operation and maintenance (O&M). Direct employment includes jobs created by the project itself, while indirect employment arises from the supply chain, and induced employment results from increased local spending by those employed directly and indirectly. For instance, the construction phase, especially offshore, often sees high local leakage, but the onshore construction and O&M stages provide more localized economic benefits. The economic impacts are typically measured in terms of Gross Value Added (GVA), with multipliers used to estimate the broader economic effects. Enhancing these benefits can involve initiatives like supply chain events, skills training programs, and local recruitment targets, which help maximize the positive economic impacts on host communities[32].

Opportunities in offshore wind development extend beyond immediate economic benefits to long-term regional growth and sustainability. The UK's ambitious target to expand its offshore wind capacity to 40GW by 2030, with an estimated £50 billion in infrastructure investment,

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31 https://group.vattenfall.com/uk/contentassets/c66251dd969a437c878b5fec736c32aa/best-practice-guidance---final-oct-2020.pdf

32 https://group.vattenfall.com/uk/contentassets/c66251dd969a437c878b5fec736c32aa/best-practice-guidance---final-oct-2020.pdf

https://group.vattenfall.com/uk/contentassets/c66251dd969a437c878b5fec736c32aa/best-practice-guidance---final-oct-2020.pdf underscores the sector's potential[33]. This growth can catalyse the development of local supply chains, port infrastructure, and related industries, fostering regional economic hubs. Additionally, the focus on local content and reducing economic leakage ensures that more benefits remain within the host regions. Strategic initiatives like the Offshore Wind Growth Partnership aim to develop the UK supply chain, enhancing global export potential and creating a competitive, innovative industry. Monitoring and adaptive management practices are crucial to ensure that predicted economic benefits align with actual outcomes, allowing for continuous improvement and maximization of socio-economic opportunities.

5.3.3 Social Impacts

Offshore Wind Farms (OWFs) have significant social impacts on local and regional coastal communities. These impacts include changes in demographics, housing, local services, and overall quality of life. Communities adjacent to OWFs often face challenges such as temporary housing shortages due to the influx of construction workers, changes in local employment patterns, and potential disruptions to traditional industries like fishing and tourism. Additionally, the visual and environmental changes brought by OWFs can affect community cohesion and residents' sense of place. Effective social impact assessments (SIAs) are crucial to identify these impacts early and develop strategies to mitigate negative effects while enhancing positive outcomes, such as job creation and local economic growth[34].

5.3.4 Monitoring Gaps

There is a lack of effective monitoring of socio-economic impacts, leading to discrepancies between predicted and actual impacts. Effective monitoring and adaptive management are essential to understand and mitigate the socio-economic impacts over the project lifecycle. This includes comparing predicted impacts with actual outcomes and adjusting strategies accordingly. Assessing socio-economic impacts presents several challenges, including the qualitative nature of social impacts and the difficulty in predicting long-term outcomes. There is a need for robust methodologies and adaptive management practices to address these challenges. In addition, monitoring and auditing are crucial to compare predicted impacts with actual outcomes, providing valuable insights for future projects.

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[33] https://group.vattenfall.com/uk/contentassets/c66251dd969a437c878b5fec736c32aa/best-practice-guidance---final-oct-2020.pdf

[34] https://group.vattenfall.com/uk/contentassets/c66251dd969a437c878b5fec736c32aa/best-practice-guidance---final-oct-2020.pdf

5.3.5 Transboundary Issues

Offshore wind projects near national borders or in shared waters may raise transboundary issues, requiring international cooperation for shared resources, environmental protection, and fair distribution of benefits. Transboundary issues in offshore wind development refer to the challenges and impacts that extend beyond national borders, affecting multiple countries. These issues arise due to the geographical spread of offshore wind farms (OWFs) and their associated infrastructure, which can influence marine environments, shipping routes, and coastal communities in neighboring nations. Effective management of these issues requires international cooperation and comprehensive planning to ensure that the benefits of offshore wind energy are maximized while minimizing negative impacts.

5.3.6 Community Concerns and Opposition

Community opposition to offshore wind farms (OWFs) often stems from a variety of concerns. Aesthetic impacts on the landscape are frequently cited, as the presence of wind turbines can alter the visual appeal of coastal areas. Additionally, there are worries about the potential negative effects on local wildlife and nature conservation. Emotional arguments, such as the attachment to the existing seascape and fears about changes to the local environment, also play a significant role in opposition[35].

5.3.7 Economic Viability and Feasibility Doubts

Some community members express doubts about the economic viability and technological feasibility of OWFs. Concerns about the financial sustainability of these projects and their long-term benefits to the local economy can lead to resistance. There is also skepticism about whether the promised economic benefits, such as job creation and local investment, will materialize or if they will primarily benefit external contractors and workers[36].

5.3.8 Impact on Local Services and Housing

The influx of workers during the construction and operational phases of OWFs can strain local services and housing. Temporary housing for construction workers can lead to increased demand and higher prices, potentially displacing local residents. Additionally, the pressure on local health,

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[35] https://group.vattenfall.com/uk/contentassets/c66251dd969a437c878b5fec736c32aa/best-practice-guidance---final-oct-2020.pdf

[36] https://group.vattenfall.com/uk/contentassets/c66251dd969a437c878b5fec736c32aa/best-practice-guidance---final-oct-2020.pdf

education, and social services can create friction between the community and developers, as residents may feel their needs are being overlooked [37].

5.3.9 Community Cohesion and Social Dynamics

The presence of a transient workforce can disrupt community cohesion and social dynamics. In traditional and close-knit communities, the arrival of a large number of external workers can lead to fears of increased crime, social conflicts, and a loss of community identity. These concerns are often exacerbated by a perceived lack of consultation and engagement from developers, leading to feelings of frustration and resentment among residents[38].

5.3.10 Importance of Early and Continuous Engagement

Effective community engagement is crucial in addressing opposition to OWFs. Early and continuous involvement of local residents in the planning and decision-making processes can help mitigate fears and build trust. Transparent communication about the benefits and potential impacts, as well as the inclusion of community benefits initiatives, can foster a sense of ownership and support for the projects. Engaging with the community through participatory approaches and addressing their concerns proactively can significantly reduce opposition and enhance the social license to operate[39].

5.3.11 Economic Leakage

Economic leakage refers to the phenomenon where a significant portion of the economic benefits generated by offshore wind farm (OWF) projects do not remain within the local or regional economy but instead flows out to other areas or countries. A significant portion of the capital expenditure for OWFs often goes to non-local suppliers, reducing local economic benefits. This issue is particularly pronounced during the construction phase of OWF projects, where most of the capital expenditure (CAPEX) often goes to international suppliers and contractors. For instance, much of the project expenditure, especially during the major offshore construction stage, leaks out of local and regional areas, with only a small percentage of the workforce and contract expenditures being local[40].

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37 https://group.vattenfall.com/uk/contentassets/c66251dd969a437c878b5fec736c32aa/best-practice-guidance---final-oct-2020.pdf

38 https://group.vattenfall.com/uk/contentassets/c66251dd969a437c878b5fec736c32aa/best-practice-guidance---final-oct-2020.pdf

39 https://group.vattenfall.com/uk/contentassets/c66251dd969a437c878b5fec736c32aa/best-practice-guidance---final-oct-2020.pdf

40 https://group.vattenfall.com/uk/contentassets/c66251dd969a437c878b5fec736c32aa/best-practice-guidance---final-oct-2020.pdf

5.3.12 Impact on Local Economies

The leakage of economic benefits can have substantial implications for local economies, particularly those in coastal regions that host OWF projects. These areas often suffer from the decline of traditional industries such as shipbuilding, fishing, and tourism. While there are significant local and regional benefits from onshore construction and the operation and maintenance (O&M) stages, the offshore construction phase sees high levels of economic leakage. This means that the potential economic uplift for local communities during the most capital-intensive phase of the project is limited.

5.4 Environmental Challenges

5.4.1 Biodiversity Impact

Offshore wind projects can disrupt local and wide-scale biodiversity, particularly affecting marine life, bird populations, and migratory species. Proper site selection, along with thorough environmental assessments, is essential to minimize these impacts and protect sensitive species and ecosystems.

5.4.2 Marine Ecosystem Impact

Offshore wind projects can affect marine life and habitats, requiring careful planning and mitigation strategies to minimize ecological disruption.

5.4.3 Seabed Disturbance

Construction and maintenance activities can disturb the seabed, affecting benthic habitats and sediment composition.

5.4.4 Visual and Aesthetic Concerns

Offshore wind turbines can alter seascapes, potentially impacting tourism and local communities' visual enjoyment [41].

5.4.5 Navigational Hazards

Wind farms can pose risks to shipping and navigation, requiring careful planning and coordination with maritime authorities.

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41 https://tj.uettaxila.edu.pk/older-issues/2016/AcceptedPapers%20No1/Off%20Shore%20Wind%20Turbines%20A%20Solution%20To%20Energy%20Crisis%20In%20Pakistan.pdf

5.5 Regulatory Challenges

5.5.1 Regulatory Frameworks

Developing clear and streamlined permitting processes, robust marine spatial planning, and supportive policies to attract investment and manage grid integration [42].Policymakers should carefully consider how their decisions affect the ability to raise financing.

5.5.2 Grid Infrastructure

Scaling up and coordinating transmission connections for offshore wind is complex, requiring robust regulatory frameworks and significant investment to ensure seamless integration with existing energy systems [43].

5.6 Planning and Assessments

5.6.1 Marine Spatial Planning (MSP)

Effective MSP is essential to balance the spatial and temporal distribution of human activities in marine areas. This helps in reducing conflicts and ensuring sustainable use of marine resources[44].

5.6.2 Environmental and Social Impact Assessments (ESIA)

Robust ESIA, including baseline surveys, are necessary to manage environmental and social risks. This process should be transparent and involve stakeholder engagement [45].

5.6.3 Data Collection and Sharing

Early-stage data collection and sharing are vital for informed decision-making and reducing project lead times. Governments can commission baseline studies to fill data gaps and improve understanding of environmental impacts [46].

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[42] https://gwec.net/wp-content/uploads/2023/08/GWEC-Global-Offshore-Wind-Report-2023.pdf

[43] https://gwec.net/wp-content/uploads/2023/08/GWEC-Global-Offshore-Wind-Report-2023.pdf

[44] https://documents1.worldbank.org/curated/en/343861632842395836/pdf/Key-Factors-for-Successful-Development-of-Offshore-Wind-in-Emerging-Markets.pdf

[45] https://tj.uettaxila.edu.pk/older-issues/2016/AcceptedPapers%20No1/Off%20Shore%20Wind%20Turbines%20A%20Solution%20To%20Energy%20Crisis%20In%20Pakistan.pdf

[46] https://tj.uettaxila.edu.pk/older-issues/2016/AcceptedPapers%20No1/Off%20Shore%20Wind%20Turbines%20A%20Solution%20To%20Energy%20Crisis%20In%20Pakistan.pdf

6 Recommendations and Way forward

Based on the findings of the current study, the following recommendations are suggested regarding the implementation of offshore wind energy in Pakistan.

1. A detailed financial model needs to be developed considering important factors like capital costs, operational expenses, revenue streams, and potential risks associated with implementation and operationalization.
2. Thorough feasibility analyses need to be conducted to evaluate the best practices and models for offshore wind development in Pakistan, and to decide whether or not it is a viable option for the country.
3. Comparison of various offshore wind technologies (fixed-bottom and floating) needs to be conducted and evaluated based on Pakistan's geographical scope, available resources, and social and environmental factors.
4. The financing mechanisms and streams also need to be identified such as public-private partnerships, international climate finance, and debt financing, which are available globally to finance offshore wind projects.
5. Bankable project proposals need to be developed to access climate and international finance which could accelerate the renewable energy integration in Pakistan through the increase in share of VRE.
6. Conducting comprehensive Social and Environmental Impact Assessments would allow policymakers and experts to assess the true cost of setting up offshore wind turbines on Pakistan's coastal belt. The impacts would include local communities, their issues like displacement, livelihood changes, and cultural heritage, as well as the environmental aspects such as biodiversity losses, marine ecosystem disturbance, bird and marine mammal impacts, and coastal erosion.
7. Before implementing new projects, the local communities, fisherfolk, and relevant stakeholders should be engaged to address their concerns regarding land use rights, livelihoods, and energy security.
8. Identify and assess potential financial, technical, and regulatory risks, and develop strategies to mitigate them.
9. Evaluate existing policies and regulatory frameworks and propose further recommendations to create a conducive environment for offshore wind energy development, including feed-in tariffs, tax incentives, and streamlined regulatory procedures.
10. Develop a transparency framework to promote investor confidence in local projects to minimize uncertainty throughout the project cycle and implementation and expedite development.

11. Address the challenges of integrating large-scale offshore wind power into the national grid, including grid infrastructure upgrades and grid stability measures to optimize existing capacities, build a more resilient energy infrastructure, and ensure seamless integration of newer wind energy projects.
12. Advocate for the creation of green jobs through the localization of the supply chain for the setup of offshore wind turbines and machinery.
13. Collaborate with and learn from best practices of developed countries like Germany, Denmark, and even China, to facilitate technology and knowledge transfer to ensure robust and efficient implementation of new projects.

7 Conclusion

Pakistan's energy mix is dominated by thermal power production, which is a source of greenhouse gas emissions and global warming. The country holds immense potential for variable renewable energy, especially in Sindh and Balochistan provinces, and along its coastal belts. Offshore wind technology presents an innovative opportunity to utilize this potential and generate clean energy that would allow the country to meet its renewable energy targets for 2030, set in its NDCs. The global trend of offshore wind development has seen a consistent increase, especially for emission-intensive industries that are more difficult to decarbonize. However, many financial, regulatory, socioeconomic, and environmental hurdles stand in the way of the implementation of offshore wind technologies.