REPORT

Offshore Wind Supply Chains in the US and Germany

Policy Recommendations and Collaboration Opportunities

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Disclaimer

This report constitutes an external input for the working group on offshore wind within the US-German Climate and Energy Partnership. It was created by adelphi upon request of the Division VB1 of the Federal Ministry for Economic Affairs and Climate Action (BMWK) for the project "Energy Cooperations with the USA and Canada" and commissioned by the Federal Office for Economic Affairs and Export Control (BAFA).

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Executive Summary

This report seeks to identify expected supply chain developments for offshore wind (OSW), focusing mostly on domestic markets in the US and Germany and relate them to the deployment targets both countries have set. In addition to evaluating existing literature, particular emphasis was placed on the perspective of market participants in both countries, with whom qualitative interviews were conducted.

Although both countries share the goal of having 30 GW of OSW capacities deployed by 2030, starting conditions differ:

In the US, the past few years have seen little actual OSW deployment. Accordingly, the domestic offshore wind supply chain is nascent, but multiple new manufacturing facilities on the East Coast (e.g., for blades, monopiles, towers, nacelle assembly) are under development/ were announced in recent years. The US offshore wind sector will have to mostly rely on imports of offshore wind turbines (OWTs) and installation ships from Europe and other markets in the short and medium term. However, experts don't see a risk of a total US market takeover by European companies and imports from other markets.

Germany, on the other hand, has seen significant deployment over the last decade (now totaling 7.8 GW), which, however, came to an almost complete standstill in 2021 and 2022. The domestic offshore wind supply chain used to be strong, but quite a number of manufacturing facilities had to close or were moved to other countries. This is partly seen as a result of market concentration processes, but experts also indicate that the repeated adjustment of certain aspects of the regulatory framework (e.g. targets and support schemes) during the last decade may have had negative effects on planning reliability and investment decisions.

As a result, gaps in Germany's domestic supply chain now exist in blade manufacturing; converter platform manufacturing; installation vessel supply and manufacturing; production of sensor technology, semiconductors, rare earths; and jacket and floating foundations.

The shortage of trained personnel is and will be a problem in both countries throughout the supply chain (engineers, project developers, electricians, mechatronics). This is due to both strong competition with adjacent industries (e.g. onshore, PV), and specific offshore challenges (general shortage of skilled workers offshore, OSW working time models). The training rate in the industry is below average (for Germany).

Based on the strong OSW expansion targets in Germany/ Europe, the US, and internationally, multiple bottlenecks in many parts of the supply chains are likely (especially in the short and medium term):

- In Germany/ Europe:
    - Particularly critical: Port infrastructure and areas; installation vessels; converter platforms; manufacturing capacities for towers, monopiles and transition pieces; permitting capacities for interconnections and onshore grid infrastructure; semiconductors and chips.
    - Likely less critical: Cables production, steel production, turbine manufacturing (but new/ adapted facilities will be necessary for larger turbine sizes).
- In the US:
    - Particularly critical: Ports and vessels, converter platforms, large forgings and castings, large steel plates for monopiles, semiconductors, rare earth elements, carbon fiber, and specific nacelle subcomponents; workforce demand.

- Likely less critical: Cables production, steel production (availability of steel in general), turbine manufacturing (nacelle assembly).

Against this background, for almost all of the experts interviewed it remains doubtful if the 30 GW targets for 2030 in Germany and the US will be achieved in time without further action and coordination efforts (though it needs to be said that these estimates in the case of Germany do not take into account the effects of the reformed Wind Energy at Sea Act that was introduced in mid-2022). That said, most experts generally trust in the performance of the industry, given a reliable framework and clear political commitment. Some concrete suggestions to work towards achieving these goals were developed as part of this analysis:

Policy recommendations and cooperation potentials:

Regulatory framework: The most important thing for the entire OSW industry in Germany and USA is to create a stable and reliable framework for OSW expansion, including well-established short-, medium-, and long-term goals, bidding procedures, and support mechanisms, as well as facilitated, accelerated, legally secure permitting processes for OSW farms, production sites and infrastructure. Based on this, the market would be able to provide the necessary capacity in many areas of the supply chains.

Government funding/ financing: In some areas, such as OSW ports and shipyards for converter platforms, targeted government support and/or financing should be considered in addition to existing OSW support schemes, so that the goals can be achieved and local value creation is ensured.

Workforce: There is a shortage of skilled workers in the US and Germany in all areas including project development and blue-collar workers, which is expected to intensify over the next few years. On top of that, the offshore industry faces additional challenges especially in construction and maintenance due to working times and conditions offshore. While training and retraining programs are available in both countries, competition with other industry branches remains an issue and targeted qualification campaigns as well as easier access for international specialists should be considered.

Supply chain capacity build-up and local content requirements: For the US, different local, regional and national content requirements for the supply of offshore wind components exist as part of state level renewable energy procurements and BOEM lease sales. In the worst case, they could lead to overcapacities in the medium and long term, inefficient supply chains and high project and electricity generation costs, and should therefore be addressed by multilevel stakeholder coordination (and potentially developing a common offshore wind strategy).

For Germany/ Europe, supply chain bottlenecks and gaps need to be analyzed more in detail and strategies should be developed to address them. As part of that, it should be analyzed where government support through funding/ financing would be necessary to overcome existing investment insecurities in the market. Some interviewed experts call for the implementation of some local content requirements in Germany as well, but harmonized with other countries in the EU, in order to incentivize local/ regional supply chain development and job creation.

Multilevel stakeholder cooperation and strategy development: There is arguably insufficient cooperation and coordination on offshore wind development both between the states themselves and between the states and the federal government in the US and (to a lesser extent) in Germany. Relevant activities could be e.g., the development of a national offshore wind strategy (similar to the H2 strategy in Germany) that includes policy harmonization to avoid fragmented state-specific policies (for the US), coordination of manufacturing and port infrastructure expansions, overall interconnection planning (for the US), development of strategic centers for decommissioning and recycling, maritime special planning etc. Such cooperation and coordination activities between decision makers from various governance levels and other stakeholders could have a positive effect on the overall development of the industry.

Port infrastructure, vessels and converter platforms: In Germany, there is currently a lack of private investments in offshore wind port projects – arguably due to a combination of long lead times, required planning reliability and competing types of use. Therefore, experts believe that the federal government should also consider participating in the financing of the port infrastructure that is critical for the energy transition. This would require coordination with the states where the ports are located, but the ongoing successful process for floating LNG import terminals could serve as an example. Other support for offshore wind ports and EU funding could be considered. Apart from that, additional areas in ports could also be achieved by encouraging tenants of container storage areas to pass on parts of their (over)capacities towards the offshore wind sector.

The construction of offshore wind converter platforms is a critical element for reaching the deployment goals, but Germany has no capacity for this. Therefore, the Federal Government could consider supporting the insolvent MV Werften in Rostock-Warnemünde in a joint effort with other stakeholders, since it is one of only two shipyards in Europe capable of building the large new converter platforms.

For the US, the Jones Act requiring certain vessels for the OSW sector to be manufactured in the US and US-flagged in order to operate from US ports is seen by many experts as an issue requiring careful consideration to ensure rapid offshore wind build-up. While some Jones Act-compliant strategies for using existing non-US-flagged vessels were found and new domestic vessel manufacturing capacities are being developed, more clarity about the application of specific regulatory requirements would help the industry to come up with workable solutions.

Rare earths and recycling: Permanent magnet generators currently used in offshore wind turbines are mostly based on rare earths mainly supplied by China. Diversifying rare earths supply chains, developing alternative, less rare earth-intensive technologies, as well as recycling processes will be crucial in the US and Germany/ Europe in order to reduce dependency of such imports from just one supplier country and promote a more sustainable industry.

There are currently only limited recycling options for fiberglass/ carbon fiber used in blades, and others, such as rare earth elements, are not typically recycled today. However, mechanical, thermal, and chemical recycling processes have been demonstrated in laboratories and pilot projects, and are at various stages of scaling up to commercial implementation. Recycling options for OWTs should be an integral element in the design of OSW farms, ports and manufacturing. Special logistics are needed. Governments should actively support the development of strategies and economic centers for decommissioning and recycling.

Collaboration opportunities:

- Knowledge and best-practice exchange on accelerating and facilitating permitting procedures as well as developing sufficient staffing for relevant administrative institutions (e.g., through workshops, study tours).

- Best-practice exchange on (re-)training and potential harmonization of training standards within the offshore wind sector, e.g., through facilitating transatlantic collaborations between educational and training organizations.
- Development of joint re-training programs for workers from fossil fuel industries with existing experience in related energy technologies industries (e.g., from the Gulf of Mexico region) to strengthen the OSW workforce and ensure a just transition.
- Facilitating direct exchange between market participants in the US and Germany (e.g. B2B sessions alongside exhibitions, fact finding missions).
- Utilize/ adapt existing stakeholder platforms (online) for knowledge sharing on available OSW experts on both sides (e.g., for maritime co-use, workforce development) and active connecting of interested parties to facilitate the needed supply chain (re-) developments.
- Knowledge exchange (also with other countries) on establishing successful cooperation and coordination processes between different, partly competing offshore wind stakeholders that include maritime co-use options and questions of environmental justice and could potentially lead to developing overarching offshore wind strategies.
- Establish joint RD&D projects to accelerate the efforts towards diversification of rare earths supply chains and the development of alternative technologies.
- Knowledge and best-practice exchange how to best organize and coordinate the interconnection of OSW farms and the necessary onshore grid buildout.
- Integrate the opportunities and existing approaches for OSW hydrogen production into the ongoing exchange on supply chains as part of an overarching energy strategy.
- Best-practice exchange and RD&D collaboration on recycling options and strategies for offshore wind components incl. decommissioning to extend the lifetime of components once produced.

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List of Acronyms

BIL	Bipartisan Infrastructure Law
BMWK	Bundesministerium für Wirtschaft und Klimaschutz [Federal Ministry for Economic Affairs and Climate Action]
BOEM	Bureau of Ocean Energy Management
CIP	Copenhagen Infrastructure Partners
CLV	cable lay vessels
COP	commercial operations plan
CTV	crew transfer vessel
EDC	electric distribution companies
FTE	full-time equivalent
GWEC	Global Wind Energy Council
GWO	Global Wind Organization
IEA	International Energy Agency
IRA	Inflation Reduction Act
ITC	investment tax credit
LNGG	LNG Acceleration Act
LROE	levelized revenue of energy
NJEDA	New Jersey Economic Development Authority
NOWTC	National Offshore Wind Training Center
NREL	National Renewable Energy Laboratory
OEM	original equipment manufacturer
OTB	Offshore Terminal Bremerhaven
OSW	offshore wind
OWT	offshore wind turbine
POI	point of interconnection
SIOW	Special Initiative on Offshore Wind
SOV	service operation vessel
WTIV	wind turbine installation vessel

Introduction

Offshore wind energy as an important pillar in clean energy transition and decarbonization is clearly on the rise – 2021 was a “new record year for offshore wind installations” (WFO 2022); many countries worldwide have recently set new offshore wind deployment targets or increased their existing targets. This is also true for the US and Germany – the US announced its target of 30 GW by 2030 in early 2021; Germany updated its existing targets in the wake of a new government taking office at the end of 2021. Both countries now share the same target for 2030.

However, increased deployment and new announcements have raised the question if the offshore wind industry would be able to satisfy the projected demand and what challenges it might have to face. This report examines some of these question with particular emphasis on the US and Germany as an input for the US-German bilateral working group on offshore wind. It does not intend to provide a full analysis of the world market but rather shed light on selected current developments in both countries and make suggestions for further cooperation to be discussed within the working group.

As the following table shows, the offshore wind supply chain includes many different business sectors:

Table 1: Overview of the OSW supply chain

Main categories	Subcategories
R&D	
Education and training	
Engineering and consulting	
Project development & planning	
Financing & insurance	
Manufacturing	Foundations/ substructures (e.g., monopile, tripod, jacket, gravity-based foundations, floating structures
	Transition pieces (incl. platforms etc.)
	Towers
	Nacelle (incl. generator, gearboxes, bearings, power electronics, forged rings and shafts, semiconductors, large castings)
	Blades
Transport & installation:	Land transport (via special trucks/ trains)
	Port handling (via heavy-lift vessel, HLV)
	Sea transport
	Installation (via wind turbine installation vessel, WTIV)
Emergency infrastructure	Rescue service providers
Grid connection	Array and export cables (via cable-laying vessels, CLV)
	Converter platform offshore, converter station onshore, substations, switchgear, etc.
Energy storage	Electrolyzers, hydrogen storage & transport
Operation & Maintenance	Service operation vessel, SOV; Crew transfer vessel (CTV)
	Helicopters
Decommissioning / repowering	
Recycling	

This report focuses primarily on sectors that are immediately relevant for build-up, i.e. manufacturing, transport and installation, grid connection and workforce.

The report is based on an evaluation of existing literature[1] which was complemented by direct responses of experts and market participants, in particular:

- Personal interviews with market participants from Germany and the US. In total, 10 interviews were conducted during July and August, 2022.
- Meetings with US OSW experts and companies in Washington DC and Atlantic City in April, 2022.
- Feedback of US participants of an offshore wind expert delegation trip to Germany in June, 2022 as part of the US-Germany Climate and Energy Partnership.

[1] Due to the rapid pace of new publications in the field, available sources at the time of writing and final publication may differ. In particular, the findings of NREL's « Supply Chain Roadmap for the US » (Shields et al. 2023), also published in January 2023, were not considered for this study.

1 Offshore Wind targets and deployment outlook worldwide, in the US, Europe and Germany

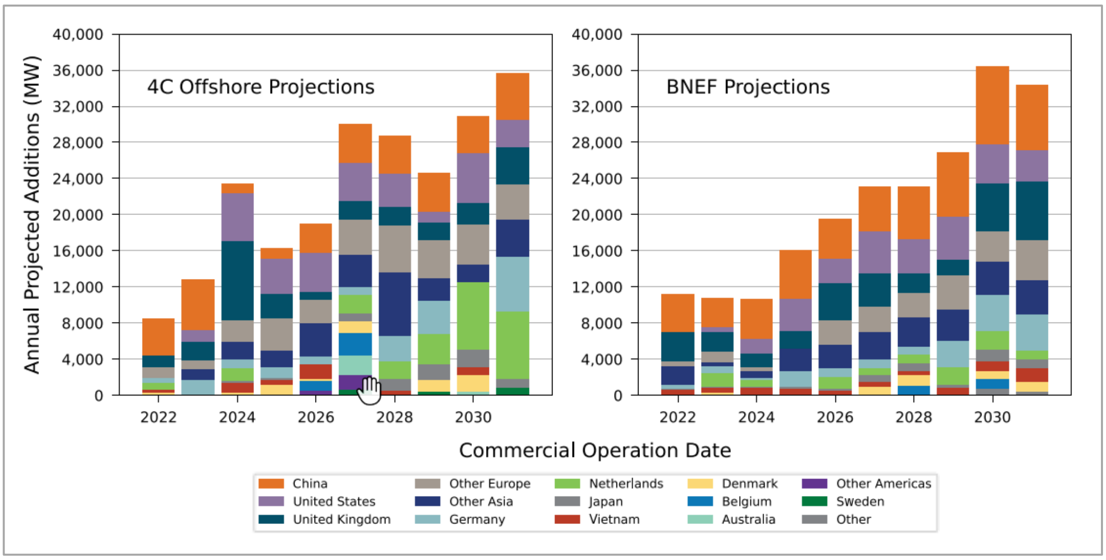
1.1 Background and global outlook

When looking at the global market for offshore wind these days, it is hard to avoid superlatives: While numbers published by different researchers differ in detail, it is clear that 2021 has seen an unprecedented deployment of offshore wind turbines, making it "the best year for the offshore wind industry" (GWEC 2022a).

At the same time, governments around the globe continue to announce new and more ambitious offshore wind deployment goals. Thus, while the IEA's "stated policies scenario" in 2019 projected an installed capacity of 165 GW worldwide by 2030 (IEA 2019), more recent estimates – taking into account technological development and government pledges – arrive at the number of 244 GW (4COffshore 2021), 254 GW (Burdock et al. 2022) or even 370 GW (GWEC 2022a).

Assuming a globally installed capacity of some 50+ GW in 2021, this comes down to an annual deployment of at least 21.5 GW on average. However, a comparison of two recent projections undertaken by NREL (Musial et al. 2022) also shows that deployment is expected to be lower at the beginning of the decade:

Figure 1: Industry forecasts for global offshore wind energy deployment to 2031



Source: Musial et al. 2022

It also becomes evident that the main potential for growth is seen in four world regions: China; Asia (excluding China); the US and Western Europe. While China has been the main driver for global development over the past four years (GWEC 2022b) and is expected to remain so for a couple more years, the deployment in China takes on a special position because of its limited degree of world market integration.

With 28.4 GW offshore wind capacity currently installed in 5,795 OWTs contributing 3% to the continent's electricity demand in 2021 (WindEurope 2022a, b), Europe is still the leading world region for offshore wind (followed closely by China with 27.7 GW). While the EU as a whole has set an overall target of 300 GW by 2050 and individual targets for 2030 do not exist in every single country, existing data still allow for pretty good projections:

Table 2: OSW capacities, targets and deployment needs in Europe

Country	Installed capacity by June 2022	Current targets for 2030	Remaining deployment needed until 2030
UK	12.7 GW	50 GW	37.3 GW
Germany	7.8 GW	30 GW	22.2 GW
Netherlands	3 GW	21 GW	18 GW
Denmark	2.3 GW	10 GW	7.7 GW
Belgium	2.3 GW	5.8 GW	3.5 GW
Others	0.4 GW[2]	43,2 GW[3]	42,8 GW
Total Europe	28.5 GW	160 GW	131,5 GW

Sources: WindEurope 2022a, b; GWEC 2022b; Musial et al. 2022; national governments, BMWK 2022a

Besides the traditional European OSW strongholds, some Western European countries with little or no prior record in offshore wind deployment have now also published targets (most notably France with 40 GW by 2050 and Norway with 30 GW by 2040). European government pledges for 2030 thus now add up to 160 GW (WindEurope 2022b). This would mean that more than half of the projected global growth until 2030 will happen in Europe, meaning the region will stay the single most important market for offshore wind in the near future.

However, as is the case with the global development, this would require a significant increase of deployment figures, especially in the second half of the decade. In the short term, WindEurope projects that European offshore wind capacities could increase by 22-28 GW until 2026, depending on how permitting, planning and supply chain issues develop. In the best case, this would entail almost a doubling of the current annual installation rate of 3.3 GW to 5.6 GW on average. The year 2026 is expected to become a "tipping point for the offshore market in Europe", since the UK will likely double its rate of installation and new/ smaller countries will (re-)join the race, such as Poland, Ireland, Belgium, Spain and Italy with modest volumes (WindEurope 2022a).

1.2 Germany

For Germany, offshore wind electricity generation plays an important role in reaching its goals of 80% renewables in gross electricity consumption by 2030, a climate-neutral electricity sector by 2035, and economy-wide climate neutrality by 2045. Also, offshore wind is seen as a factor

[2] This includes Sweden (192 MW), Finland (71 MW), Italy (30 MW), Ireland (25 MW), Portugal (25 MW), Norway (6 MW), Spain (5 MW), and France (2 MW).

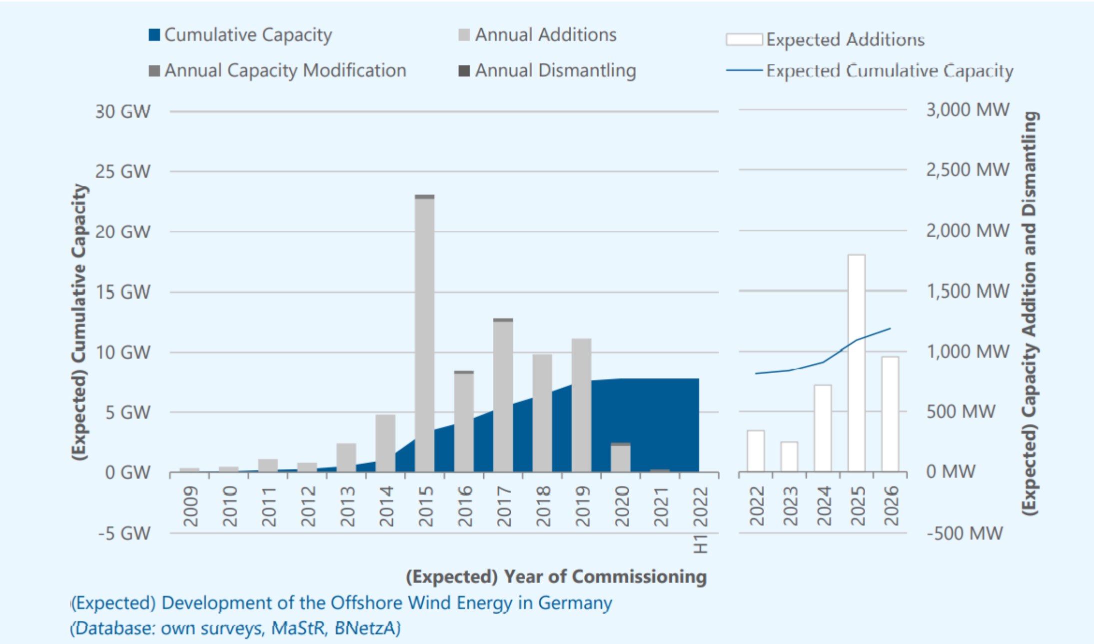
[3] The figure was deducted from WindEurope 2022b, as not all of the remaining countries have set targets for 2030. It includes: Poland (5.9 GW), Spain (3 GW floating by 2030), Portugal (3-4 GW by 2026), Norway (30 GW by 2040), France (5 GW by 2028; 40 GW by 2050), Italy (3.5 GW), Greece (2 GW), Ireland (7 GW)

of reducing volatility in a grid with a high percentage of renewables. It is also expected to help bring down costs and increase flexibility through international grid connections and potentially offer an additional possibility for producing green hydrogen in the future.

Germany has seen a relatively quick buildup of offshore wind capacity in the last decade. As of December 31, 2021, the total installed offshore wind capacity amounted to 7.8 GW in 1,501 turbines (up from next to zero in 2010), contributing 4.9% to the net electricity generation. Most of the installed capacity of the 27 operating OSW projects is located in the North Sea (6.7 GW), while the Baltic Sea plays a minor role with 1.1 GW. With 24.0 TWh produced in 2021, offshore made up more than 20% of total wind energy produced.

In 2021, no new OWT were installed, but some received a capacity upgrade. The total installed capacity is expected to increase to almost 12 GW by the end of 2026, if all projects awarded in 2017, 2018 and 2021 (eleven wind farms with a total capacity of around 4 GW) are fully realized and grid connected (Deutsche Wind Guard 2022).

Figure 2: (Expected) Development of Offshore Wind in Germany



Source: Deutsche WindGuard 2022

As part of the federal government's coalition agreement and latest amendment to the Wind Energy at Sea Act, Germany's offshore wind capacity deployment targets were increased strongly to at least 30 GW by 2030, 40 GW by 2035, and 70 GW by 2045 (previously they were set at 20 GW by 2030 and 40 GW by 2040). To reach those targets, new tender rounds for 8-9 GW in 2023/2024, 3-5 GW 2025/2026, and 4 GW from 2027 onwards are planned. Based on that, most of the expected offshore wind deployment until 2030 will have to happen in the last years of this decade due to long lead times for planning and construction:

Table 3: Expected OSW deployment in Germany

Years	Expected capacity additions (GW)	Expected average turbine size (MW)
2021 - 2025	3.1 - 3.5	11.2
2026	1	14+
2027	0.9	
2028	2.9	16
2029	6	
2030	8	
2031 - 2035	6	20

Sources: WindGuard 2022; Agora Energiewende 2022.

In July 2022, the Federal Maritime and Hydrographic Agency (BSH) published a new draft site development plan (FEP) (expected to come into force in 2023), which already specifies OSW areas with a planned total capacity of approximately 60 GW. For the 70 GW goal for 2045, further areas have to be found, meaning that co-use of other areas is necessary or that OSW needs to be prioritized in those areas.

1.3 USA

The US government targets 100% carbon pollution-free electricity by 2035 and economy-wide net zero greenhouse gas emissions by no later than 2050 (The White House 2021b). As part of that, the Biden Administration has set a national goal of 30 GW of OSW capacities installed by 2030 (largely met using fixed-bottom technology), which, if achieved, could "unlock a pathway to 110 GW by 2050" (The White House 2021c). In addition to that, the Biden administration announced a new goal in September 2022 to deploy 15 GW of floating offshore wind capacity by 2035 and reduce the costs of these technologies by more than 70% in the same timeframe through a Floating Offshore Wind Shot program (The White House 2022a).

Until today, the US has had very limited fixed-bottom OSW deployment with only 42 MW installed in two projects off the coasts of Rhode Island and Virginia (Block Island, 30 MW; Coastal Virginia Offshore Wind Pilot Project, 12 MW) and no floating OSW capacity so far (Musial et al. 2022).

However, there are many wind farms and OSW areas under development. A recent NREL study found that if all projects of "awarded, soon-to-be-awarded, and anticipated lease areas progress with realistic deployment and permitting schedules" and "without significant disruptions", the 30 GW goal by 2030 is reachable, as "deployment will rise to over 6 GW annually" in 2028 and at least 4–6 GW per year after 2030. Such annual growth year-by-year after 2030 would "be required to reach a cumulative capacity of nearly 60 GW by 2035 and at least 110 GW by 2050" (Shields et al. 2022).[4] Musial et al. similarly estimate that US OSW capacities could cumulatively reach 28.8 GW by 2030 (Musial et al. 2021).

As of August 2022, the US OSW project pipeline (including existing, approved and unapproved projects as well as existing wind energy lease and call areas) was around 40 GW, most of

[4] According to Shields et. al. (2022), these deployment numbers should not be considered as a forecast but be seen as "a realistic scenario that can be used to evaluate the demands that will be placed on the supply chain" (Shields et. al. 2022)

which is located off the coast of New York, Massachusetts, and New Jersey, North Carolina and Virginia. A major driving force for this deployment are individual state commitments to procure offshore wind energy capacities for their electricity sector, which as of May 2021 amount to around 40 GW OSW capacities by 2040 (Musial et al. 2021). The Bureau of Ocean Energy Management (BOEM) has announced plans to hold multiple new lease area auctions between 2022 and 2025 (Shields et al. 2022).

1.4 Supply Chain Implications

The global OSW industry currently faces multiple challenges: The COVID-19-related supply chain disruptions and the following sudden recovery has resulted in very strong competition among different industries for raw materials, including steel, concrete, copper, nickel and rare earth elements, and an ongoing bottleneck in manufacturing and shipping capacity. Therefore, freight costs and commodity prices increased strongly, putting further price pressure on turbine and component suppliers and developers, which are already struggling by the “race to the bottom” conditions resulting from the auction-based market designs. As examples, between the beginning of 2020 and the end of 2021, prices for key rare earth elements have tripled and steel prices have increased by around 50% (and have seen further dramatic increases since the Russian invasion of Ukraine) (GWEC 2022b).

According to WindEurope, built offshore wind farms in Europe currently have an average power rating of around 8.5 MW (2021) and reach capacity factors between 42 and 55% (WindEurope 2022a). Further growth of turbine sizes is generally expected, although analysts differ to some extent in their prediction of future capacities. Deutsche WindGuard expects average sizes of 11 MW by 2025 (Deutsche WindGuard 2022), GWEC expects 12 MW by 2025 (GWEC 2022a). DOE expects 12 – 15 MW turbines to be “available for purchase by 2024 or sooner” (Musial et al. 2021) – which corresponds to the announcements of German developer EnBW to use 15 GW turbines for a project coming online in 2025. All in all, even by conservative estimates it seems to be fair to assume an average turbine size of 12 MW until 2030, leading to the following assumptions:

Table 4: Assumptions for components and materials needed for 1 GW of OSW capacity (fixed foundation)

Component type	**Number**	**Commodities** (based on GWEC 2022b)
Turbines	83	Steel: 198,900 t Electronic Scrap: 11,050 t Glass Fiber Reinforced Plastic: 8,840 t Others: Copper, Aluminum, Carbon Fiber Reinforced Plastic, Rare Earth, Lead, Concrete
Foundations	85 (incl. substations)	

A very rough estimate thus leads to the assumption that until 2030 roughly 9,000 OWTs and 200 offshore substations will be needed in Europe alone, for the US, studies by NREL and SIOW estimate more than 2,000 OWT and 53 substations (Shields et al. 2022; SIOW 2021).

While it is clear that this snapshot leaves aside important elements of the supply chain, such as cables and vessels, it can still give an impression of the challenges, especially given price increases of 50% for steel (2020 – 2021) and 60% for copper (GWEC 2022a).

The full dimension of the challenge becomes evident when comparing the targets set out to the developments in the past and the implications for the supply chain. Thus, over the past six years (2017-2022), about 17 GW of OSW capacities were added in Europe, meaning the suppliers (mostly European) had to satisfy a demand of 2.7 – 4.1 GW (2.8 GW on average) and 130 – 500 turbines (414 on average) per year.

The 17 GW are made up of 54 offshore wind farms, roughly 2,500 turbines, with an average turbine capacity of 7 MW, as well as 48 substations and converters (4COffshore n.d.; WindEurope 2022b). In addition to these wind farms that have already been fully commissioned, 24 projects are currently in the construction or pre-construction phase. They comprise around 1,000 turbines and 19 substations and converters; the turbines now used have an average capacity of 11.5 MW (4COffshore n.d.)

Put very simply, the existing capacity of suppliers based in Europe would have to roughly double by the middle of the decade (in terms of MW) compared to the demand in the past, which implies significant additional deployment (in terms of OWTs) even considering expected increases in nameplate capacity. Towards the end of the decade, annual capacity would need to grow by 5 to 10 GW per year (!) and the number of OWTs installed per year would need to increase approximately four- to six-fold compared to the average of the last years in order to satisfy the need implied by government targets in Europe alone (comp. Table 5).

Table 5: Capacity additions expected/ needed to reach government targets

Year	Projected/ needed annual capacity additions (GW)		Expected average turbine capacity (MW)	Number of OWTs to be installed per year	
	Europe	US	Global	Europe	US
2022	3.5	0	8	438	0
2023	4.4	1	9	488	111
2024	4.1	4.6	9	456	511
2025	5.4	4.8	13	415	370
2026	10.4	4.5	14	743	321
2027	15*	5.9	15	1,000	393
2028	20*	3.7	15	1,333	247
2029	30*	1.8	16	1,875	113
2030	40*	6	16	2,500	375
Cumulative additions (2022- 2030)	133*	32	NA	8,777	2,376

Sources: For Europe: WindEurope 2022a's Realistic Expectations Scenario for 2022-2026 and approximations* based on WindEurope 2022b for 2027-2030. For US: 4C Offshore 2022 (based on figures by Musial et al. 2022). Average turbine capacity assumptions based on Musial et. al. 2022, GWEC 2022a Energy Innovation NL 10.5.2022, US Wind Inc. 2022, NREL 2022

Adding US deployment goals to this should give a rough idea of the common challenge for the industry, considering large-scale imports from China will remain limited for a number of reasons.

2 Overview of US Offshore Wind Supply Chains and Challenges

2.1 Status quo

The implications of OSW deployment targets on the development of a US supply chain have been extensively covered in recent months (esp. Baranowski et al. 2022, Igogo 2022, SIOW 2021, Shields et al. 2022).

While it is clear that near term US OSW deployments will heavily rely on existing international supply chains, the implications in the previous chapter suggest that suppliers from Europe and Asia will not be able to cover US demand in the medium and long term given the rising demand in other parts of the world (see also SIOW 2021). Building a domestic supply chain will therefore be vital not only for avoiding supply chain bottlenecks and ensuring sustained high OSW deployment levels, but also to potentially lower project costs and risks and create local economic benefits (Musial et al. 2021; Baranowski et al. 2022; Shields et al. 2022). As the potential for utilizing existing onshore wind manufacturing capacities is limited for various reasons (Baranowski et al. 2022), the build-up of the industry will have to happen in large parts from scratch.

2.1.1 Manufacturing capabilities

At the time of writing, existing OSW supply chain capacities in the US are very limited. The only operational US manufacturing facilities are for array and export cables (Nexans High-Voltage Cable Facility, Charleston, South Carolina and Kerite, Marmon Group, Vineyard Wind in Kerite, Connecticut) and offshore substations (Kiewit in Ingleside, Texas) (Musial et al. 2022). In particular, Nexans subsea cable plant in Charleston, South Carolina based on an existing plant for land-based transmission, will deliver up to 1,000 kilometers of cables for Ørsted's and Eversource offshore wind farms in North America up until 2027. Starting in 2022, the plant will first supply an offshore windfarm in the UK and then will also be the preferred supplier for Equinor's Empire Wind 1 and 2 projects (Offshore Engineer 09.11.2021; Shields et al. 2022). Kiewit Offshore Services, Ltd. is constructing the first US-built substation (to be installed by summer of 2023) for the 132-MW South Fork Wind project in New York by Ørsted and Eversource (Eversource 25.08.2021).

However, multiple investments with a total value of around $1.2 billion (through May 31, 2022) in new domestic manufacturing facilities (and adaptations of existing facilities) especially for tier 1 offshore wind components and ships were announced and started over the last 2-3 years, mainly driven by the US states' local content requirements as part of their power offtake agreements (Musial et al. 2022; Shields et al. 2022):

Table 6 Announced manufacturing facilities in the USA

Type	Company	Location
Blades	Siemens Gamesa	Portsmouth Marine Terminal, Virginia
Substations	Kiewit Offshore Services	Ingleside, Texas
Nacelles (final assembly only)	Vestas & Atlantic Shores	New Jersey Wind Port, NJ
	GE & Orsted	
Transition pieces	Marmen Welcon & Smulders	Port of Albany, New York
Towers	Marmen Welcon & Equinor	Port of Albany, New York
Monopiles	EEW & Orsted	Paulsboro Marine Terminal, NJ
	US Wind	Tradepoint Atlantic, Maryland
Gravity based foundations	Cobra, Esteyco, Equinor	New York
Foundations	Ørsted & Eversource	Port of Providence, Rhode Island
Secondary Steel	Eversource & Ørsted	Port of Coeymans, New York
Array and export cables	Hellenic Cables & Orsted	Tradepoint Atlantic, Maryland
	Kerite, Marmon Group & Vineyard Wind	Kerite, Connecticut
	Nexans	Charleston, South Carolina
	Prysmian & Avangrid	Brayton Point, Massachusetts

Sources: Baranowski et al. 2022; Musial et al. 2021, 2022; Eversource 25.08.2021.

Despite those facility announcements, many tier 2 and tier 3 components are not manufactured in the US yet for different reasons, representing a particular challenge to establishing a domestic supply chain:

As part of the **nacelles** of OWTs, direct-drive **permanent magnet generators**, commonly used in Europe and Asia as of today, are so far not produced domestically in the US. Furthermore, the required rare-earth metals for those generators are not mined domestically in sufficient quantities to meet the demand for the offshore wind sector and specialized processing techniques are not available in the US (Shields et al. 2022). Their global production and processing are mostly concentrated in China, which made up more than 60% of rare earth production in 2019 and, in recent years, has limited exports of such materials to the US as well as increased tariffs. For the highest capacity turbines in the coming years, however, manufacturers are also pursuing the development of **novel superconducting wind generators** that are lighter and do not depend on rare earth magnets. Some US superconducting companies (e.g., GE, AMSC) have expressed interest in this technology for the OSW sector, but it is unclear whether these new generators would be manufactured in the US or not (Baranowski et al. 2022).

Large bearings (yaw and pitch bearings), used in the nacelle, are not produced domestically at the scale required for OWTs and current market conditions have not motivated US manufacturers to develop manufacturing capacities for these sizes. Similarly, manufacturing of large hub castings, is limited and no serial production exists in the US, since the foundries needed to manufacture them may not be developed because of their significant environmental impact (Shields et al. 2022; Baranowski et al. 2022).

As part of the **foundations** and **towers**, **large steel plates**, which are rolled into circular monopiles or tower sections are not widely fabricated domestically at the size or type of steel required and the steel automation capabilities necessary for processing are less advanced in the US than they are globally. Therefore, current OSW projects in the US are based on imports from European and Asian markets for those subcomponents.

For **semiconductors** and **communications equipment** in wind turbines, the US dependence on imports from foreign markets has increased strongly over the last decades and currently a global shortage of semiconductors exists. Most advanced semiconductor manufacturing capacity is concentrated in East Asia and the US share of global semiconductor production has declined from 37% in 1990 to 12% currently (Baranowski et al. 2022). Barriers to domestic manufacturing include high capital and R&D costs, the need for constant improvements in factories, and rapid chip obsolescence due to improving designs (White House 2021d; Baranowski et al. 2022)

As part of the **processed materials** needed for the OSW sector, **steel** makes up most of the weight of OSW farms as it is the main material used for foundations, towers, and castings. While the US production capacity of steel is significant and imports only represent circa 12% of US consumption (USGS 2021), there is limited domestic production of specialty steels such as electrical steel. For **glass or carbon fiber composites (for blades)**, **concrete** (for gravity-based foundations), and **polymers** as well as their source materials, studies expect that the domestic supply chain will be able to meet the demand of the offshore (and onshore wind) industry under the planned deployment over the next years (Baranowski et al. 2022). Some materials for the production of array and export cables, such as specific lead alloys and plastics used for insulation, need to be imported as they are not currently produced domestically (Shields et al. 2022).

2.1.2 Supply Chain Example: Vineyard Wind 1 (800 MW)

Located 24 km (15 miles) off the coast of the island Martha’s Vineyard and 56 km (35 miles) from mainland Massachusetts, Vineyard Wind 1 will be the first commercial-scale OSW farm in the US with 800 MW installed capacity. The almost 3 billion dollar-project developed by Vineyard Wind LLC, a joint venture owned 50% by Copenhagen Infrastructure Partners (CIP) and 50% by Avangrid Renewables (a subsidiary of Iberdrola), obtained the lease area in January 2015, completed state, regional and local permitting in Spring 2020, received an interconnect agreement from the New England ISO in July 2020, and approval of the construction and operation by BOEM in May 2021, reached financial close in September 2021, and is planned to be fully commissioned by April 2024 (BOEM n.d.; Vineyard Wind n.d.a).

With a revision to its commercial operation plan (COP) in December 2020, Vineyard Wind switched from using MHI-Vestas 9.5-MW wind turbines to 62 General Electric 13-MW Haliade-X wind turbines (produced in Saint-Nazaire, France) (Musial et al. 2021). Their installation at an average water depth of 42 m based on monopiles (produced in Spain) by Windar Renovables will be done through a Jones-Act-compliant strategy with US-flagged feeder vessels by FOSS Maritime Company LLC to transport the turbines from the port of New Bedford to a foreign-flagged jack-up installation vessel on-site provided by DEME Offshore US LLC (4C Offshore 2022a; Windar Renovables n.d.).

The wind farm will be connected to the New England electricity grid through 66 kV inter-array cables, just one offshore substation (800 MW conventional Electrical Service Platform), and two submarine 220 kV export cables (AC), provided and installed by the Prysmian Group S.p.A. (ITA) (BOEM n.d.; Vineyard Wind n.d.a; 4C Offshore 2022a).

2.1.3 Excurse: The US onshore wind manufacturing industry

For onshore wind energy, large shares of major components are produced domestically and the DOE describes the US manufacturing industry as "currently competitive" regarding towers, foundations, nacelle assembly, some nacelle and blade subcomponents, certain processed materials such as steel, certain raw materials, and in recycling capacity (Baranowski et al. 2022). However, the US (partly) relies on imports for certain subcomponents, such as forged rings and shafts, large castings, as well as processed and raw materials, such as rare earth elements. Analysts estimate that a typical US onshore wind project sources around 60% of its components (by dollar value) domestically (Baranowski et al. 2022; Goldie-Scot et al. 2021).

For **wind turbines**, GE, Siemens Gamesa Renewable Energy and Vestas are the primary supplier to the US onshore market. All those original equipment manufacturers (OEMs) have significant operations as well as manufacturing capacities in the country. The German Nordex Group also supplies a significant number of turbines to the US (12% of total market share in 2021), but with little domestic manufacturing presence. Chinese OEMs, which are often cheaper producing, only have a very small market share in the US, since almost all of their products go to the Chinese market and because Western banks will not finance them (Baranowski et al. 2022; Goldie-Scot et al. 2021).

German companies are important suppliers of parts of the nacelles for onshore wind turbines (but not for towers and blades). They are leading in supplying bearings to the US onshore wind sector, are second place behind China for supplying gearboxes, and made up 9% of imported generators to the US in 2019 and 2020 (Baranowski et al. 2022).

Onshore wind **towers** manufactured in the US "are seeing some pressure from low-cost imports from Asian markets" due to lower cost for steel and labor, but "antidumping and countervailing duties orders are in place on such imports from China, Vietnam, Canada, Indonesia, Korea, India, Spain, and Malaysia" (Baranowski et al. 2022). In blade manufacturing, the US is currently losing competitiveness against Europe, Mexico, and other markets due to lower manufacturing and labor costs. US manufacturing of forged rings and shafts for subcomponents, such as the main generator shaft, tower flanges, yaw, pitch, main bearings, has lost market share to foreign producers (Baranowski et al. 2022; Fullenkamp and Holody 2014).

2.1.4 Workforce

Similar to the OSW sector in general, the required domestic workforce is really just starting to develop in the US, as the first large OSW farms and related manufacturing facilities are being established. OSW component manufacturing involves a **diverse workforce**, from plant-level workers (e.g., welders, electricians, machine operators, assemblers), plant-level management (production engineers, manufacturing engineers, and plant and operations managers), to design and engineering (design engineers, testing engineers, supply chain analysts), quality and safety, and facilities maintenance (supervisor and technician roles) (Baranowski et al. 2022). Apart from the direct jobs, which fabricate or assemble final tier 1 components at a manufacturing facility, there are typically even more **indirect jobs** related to the OSW sector, which produce parts or materials for a major component. Those indirect jobs can therefore significantly increase the local economic benefits of the sector if included in a more comprehensive domestic supply chain (Shields et al. 2022).

Many experts and studies state that there is a **shortage of qualified workers** in many of those relevant job categories (mentioned above) in the US, similar to the situation in Germany, and that more workforce training or re-training is urgently and critically needed to jump-start the domestic supply chain, reach the OSW deployment goals and meet the related high workforce demand in the short, medium and long term (Shields et al. 2022; Baranowski et al. 2022; Atlantic Council 2021). Stefek et al. (2022) estimate that the US OSW sector (incl. fixed-bottom and floating projects) could on average support between 15,000 and 58,000 jobs in full-time equivalents (FTEs) annually through 2030, depending on the annual deployment rate, the share of domestic content, and on how quickly US manufacturing facilities are built (Stefek et al. 2022). The White House even expects that meeting the 30 GW by 2030 goal will lead to "more than 44,000 workers employed in offshore wind directly by 2030 and nearly 33,000 additional jobs in communities supported by offshore wind activity", as well as "77,000 offshore wind direct jobs and more than 57,000 additional jobs in communities supported by offshore wind activity by 2050" (The White House 2021b). The fabrication and assembly of nacelles and their subcomponents, e.g. generators and gearboxes, which for onshore wind have been mostly imported to the US, is estimated to create the highest job demand potential in the sector, followed by the production of monopiles, towers, and rotor blades. Plant-level workers will likely provide the largest part of this workforce growth (Shields et al. 2022).

The most relevant actors in the growing field of **workforce training** for the OSW sector in the US are educational institutions (such as universities and community colleges), unions, OEMs, and OSW developers. Unions play an important part in that, since they usually have available training facilities and are already working on re-training their workers to switch from declining fossil fuel-based jobs to the renewable energy sector, amongst others. Over the last years an important trend is developing in the US: OSW developers and labor unions (present in many East Coast states) are forming so-called "union-company/ project labor agreements"[5] for the new economic activities to comply with labor- and equity-related requirements in state procurements and harbors, ensure opportunities for union labor in the new sector, establish necessary skills training programs, implement high safety standards, and promote a more diverse workforce, amongst other reasons (Atlantic Council 2021).

As a result of such agreements and additional state and federal efforts, multiple training programs, institutions, and initiatives for OSW workforce development are being established, such as:

- the nation's first Global Wind Organization (GWO) Training Center for offshore wind located on Long Island.
- the National Offshore Wind Training Center (NOWTC) at Suffolk County Community College on Long Island ($10 million by Ørsted & Eversource as part of Sunrise Wind project).
- the New York Offshore Wind Training Institute (OWTI; $20 million) (to provide funding for the training of 2,500 New York workers for offshore and onshore projects through other organizations like community colleges).

[5] These include: Ørsted and North America's Building Trades Unions (NABTU) in 2020; Dominion Energy and Virginia State Building and Construction Trades Council, International Brotherhood of Electrical Workers, and Laborers International Union of North America Mid-Atlantic Region in 2021 for the onshore grid interconnection work of Coastal Virginia Offshore Wind project; Vineyard Wind and Massachusetts Building Trades Council.

- the New Jersey Offshore Wind Safety Training Challenge ($3 million by NJBPU), a workplace apprenticeship program as part of the NABTU-Ørsted agreement, and
- the Labor Energy Partnership (NYSERDA n.d.; NJEDA 04.02.2021; Atlantic Council 30.03.2021).

However, it appears that there is no common understanding on and harmonized system for OSW trainings and standards yet in the US, as multiple experts state.

2.1.5 Ports and vessels

As of today, few existing of the East Coast ports and none of the West Coast ports have sufficient capabilities to fully support OSW activities (Shields et al. 2022; Parkinson and Kempton 2022). Shields et al. 2022 found that out of 22 eligible East Coast ports, currently "only one port (Portsmouth Marine Terminal in Virginia) has the existing capabilities to support loadout of wind turbine installation vessels" (WTIV) and only five ports[6] may be ready to support alternative feeder barge strategies to install for fixed-bottom OWTs mostly due to limited berth/channel depth, quayside length, and bearing capacity (Shields et al. 2022). One of them is the port of New Bedford, MA, that will be used to transport the 13-MW wind turbines for the Vineyard Wind project with US-flagged feeder barges to a foreign-flagged WTIV on-site for installation (Shields et al. 2022; Windar Renovables n.d.)

On the **East Coast**, developers and state bodies are making investments in port infrastructure to support the emerging OSW sector either through upgrades or greenfield construction in anticipation of the first round of projects (Musial et al. 2022). For example, the New Jersey Economic Development Authority (NJEDA), is constructing the New Jersey Wind Port, the nation's first purpose-built OSW marshalling and fabrication port (incl. assembly of nacelles) located at the Delaware River ($300-400 million, 220 acres, to be ready by 2024), and the State of Connecticut together with Gateway Terminal, Ørsted, and Eversource are redeveloping the State Pier in New London into a heavy-lift capable port for the OSW sector ($250 million, planned completion by spring 2023) (NJEDA 18.07.2022; CT Port Authority n.d.). On the **West Coast**, port upgrades are planned in Coos Bay, Oregon, and Humboldt, California, amongst others, to support future floating OSW marshalling activities (Shields et al. 2022). Lantz et al. (2021) found that meeting the 2030 deployment target would require port upgrades for offshore wind activities of at least $375 million–$500 million between 2023 and 2030 beyond current plans and up to $3.1 billion from 2041 to 2050 for the 110 GW scenario in 2050 (Lantz et al. 2021).

Port development is supported with funding from the US federal government and multiple state governments. For example, the Bipartisan Infrastructure Law (BIL) provides up to $2.25 billion for the Department of Transportation's Port Infrastructure Development Program, and New York State is investing $200 million in offshore wind port infrastructure through a competitive solicitation process to allocate the funds (NYSERDA n.d.)

Constructing OSW projects requires specialized vessel types, and studies show that the US and global **vessel supply** for the sector will need to increase substantially to accelerate OSW deployment and meet the goals. Shields et al. 2022 found that WTIV pose the biggest risk followed by feeder barges, cable lay vessels (CLV), service operation vessels (SOV), and scour protection vessels. For Jones-Act-compliant WTIVs, for example, the estimated peak demand to 2030 are five to seven, none exists, the estimated construction time is three years with estimated cost around $250–$500 million, and currently just one is under construction

[6] These are New Bedford, MA, New London State Pier, CT, Portsmouth Marine Terminal, VA, New Jersey Wind Port, NJ

(Charybdis in Brownsville, Texas by Dominion Energy and others) with a planned completion by late 2023. The rapid commissioning of additional WTIVs would be important to reach the deployment goals (Musial et al. 2022). While WTIVs do not necessarily need to be Jones-Act compliant if a feeder barge installation strategy is used, building them in the US may make it more likely that they are used for domestic projects and not in other, more mature markets (Musial et al. 2022; Lantz et al. 2021; Shields et al. 2022).

The **Jones Act** requires vessels that ship merchandise and passengers between two US points/ports to be US built and registered (flagged), as well as owned and crewed by US citizens or residents. The act is a “unique feature” of the US OSW market that can be a major driver in the build-up of the domestic supply chain but also lead to bottlenecks, if the construction of new US-flagged vessels is not fast enough and if the global market for foreign-flagged vessels is tight, as experts worry (Musial et al. 2021). Some interviewees also mentioned that a further tightening of the Jones Act requirements, as debated by some political actors, could significantly slow down the envisioned OSW deployment in the US.

Many of the first US OSW projects will rely on **foreign-flagged WTIVs** supported by US-flagged feeder vessels. Additional investment in feeder vessels will be necessary to support larger sized wind turbines and the expanded project pipeline. Multiple construction projects for large feeder vessels, crew transfer vessels, service operations vessels with commissioning dates before 2025 were started in the US over the last years (Baranowski et al. 2022). The procurement of those types of Jones-Act-compliant vessels seems to be less of a challenge than for WTIVs because of multiple ongoing projects and lower construction costs (Musial et al. 2021). In June 2022, the Biden Administration announced “Priority Financing for Offshore Wind Vessels” through the Federal Ship Financing Program, which assists the domestic shipbuilding industry by providing support for modernization of shipyards and to build and retrofit vessels, amongst others (The White House 2022b).

2.1.6 Grid connection

The current OSW interconnection approach of the first US projects is mostly based on using offshore substations to transform the electricity to high-voltage, e.g. 138 kV (South Fork Wind), 220 kV (Vineyard Wind 1), and transmit it via alternating current (AC) export cables to an onshore point of interconnection (POI) on a project-by-project basis (Musial et al. 2022; South Fork Wind n.d.; Vineyard Wind n.d.b).

However, studies found that the existing POIs may not have sufficient capacity available to connect every planned project individually and that shared transmission development should be preferred and incentivized, since it would reduce the number of cables and beach landings, improve reliability, and have fewer impacts on the marine environment and coastal communities (Musial et al. 2022).

2.2 Outlook on supply chain vulnerabilities, gaps, and 2030 targets

Recent studies and expert opinions suggest that without supply chain constraints, achieving 30 GW installed OSW capacity by 2030 will be challenging but theoretically possible, since the awarded and soon-to-be-awarded lease areas have sufficient capacity to achieve this target (Shields et al. 2022).

However, in practice, multiple experts doubt that the deployment can be fast enough to reach 30 GW by 2030 in time because of expected supply chain, transmission, permitting, coordination and policy change-related issues and resulting project delays. Therefore, they hold the target as "very aspirational" and believe that **30 GW will only be achieved at a later point**. Regardless of the timing, many agree that reaching the goal will likely require substantial investments in the domestic supply chain (including manufacturing facilities, ports, vessels and workforce training) and the development in complementary sectors, such as offshore wind permitting and transmission grid development. Furthermore, it will be important to develop the domestic supply chain "in such a way to be flexible enough to adapt to new and larger technologies" (Shields et al. 2022), to offshore hydrogen production and to potential exports to other markets. For the years after 2030, substantial "leasing of new areas from 2022 to 2025 will be required to maintain a consistent deployment rate", which will be critical for developing a robust domestic supply chain based on a predictable, longer-term demand for components (Shields et al. 2022).

According to research and experts, the most crucial US OSW supply chain vulnerabilities are/ will be:

- Potential large investments uncertainties in the domestic supply chain build-up (incl. vessels and converter platform/ substation construction) due to concerns regarding regulatory- and support framework changes, project pipeline uncertainties, and competing state-level content requirements.
- Large new workforce demand and urgent need for new training and re-training programs to meet the deployment goals (Baranowski et al. 2022).
- Higher demand for necessary marshalling ports than currently available or planned and lacking commitment from port authorities and port investors to develop suitable land for OSW purposes (Parkinson and Kempton 2022).
- Lack of access to vessels for OSW deployment in the short and medium term (especially for WTIVs), also due to Jones Act requirements and high demand on global markets (Baranowski et al. 2022).
- Domestic supply chain gaps/ bottlenecks currently exist for multiple important tier 2 components, such as rare earth magnets for direct drive generators, large bearings used in the nacelle, large hub castings and flanges, large steel plates for monopiles, and semiconductors.
- Risk of shortages of rare earth magnets, no domestic rare earth mining and processing, and high dependence on imports from Asia (Baranowski et al. 2022).
- Permitting delays resulting from lawsuits, conflicting maritime interests, complex, multilevel administrative processes, and staffing problems in relevant agencies.
- Policy coordination problems between different government agencies potentially leading to OSW deployment delays, e.g., fishing sector regulations requiring OSW vessel speed reductions in certain areas.
- Low labor costs from overseas competitors can potentially threaten the competitiveness of domestic manufacturing for the OSW sector and investments in US facilities especially for labor-intensive processes such as blade and tower manufacturing (Baranowski et al. 2022).
- Complex planning and coordination processes at the state, federal and utility levels pose a large challenge for the necessary shared transmission development to shore, with

respect to maintaining project timelines, and onshore with respect to system integration and required grid upgrades (Musial et al. 2022).

The near-term US OSW deployment will be mostly based on **international supply chains for major components**, installation vessels, and engineering expertise due to the nascent stage of the domestic supply chain. Relying on existing US onshore wind manufacturers will be difficult for multiple reasons: First, the components for offshore wind turbines are larger than for land-based wind turbines, leading often to the need for the establishment of new and larger manufacturing sites as well as exacerbating the transportation problem over land. Second, they are concentrated close to the Great Plains, which means that transporting large components over land to offshore sites will be challenging and costly (Baranowski et al. 2022).

While multiple manufacturing facilities for **tier 1 components** are being developed in different US states, only a few facilities are currently operational and many more new facilities will be needed for a mature domestic OSW supply chain. Additionally, experts see the wide range of **tier 2 and tier 3 components** required, as an opportunity for some companies to adapt/ repurpose their existing capabilities, such as for secondary steel production based on heavy industry manufacturing sites, or build new facilities from scratch as first-movers to support the growing market (Shields et al. 2022; Baranowski et al. 2022).

3 Overview of Germany's Offshore Wind Supply Chain and Challenges

3.1 Status quo

3.1.1 Overall situation

Based on stable deployment numbers in Germany in the last decade (comp. section 1.2), an extensive and capable local offshore wind industry was able to develop in Germany, complementing "big players" focusing on international markets. According to a recent analysis by wind:research, 862 companies with a total of 21.400 employees were active in the sector in 2020, roughly 24% of which were working exclusively in offshore wind (wind:research 2022). German companies cover most sectors of the value chain, are distributed throughout the whole country (not just along the coastlines) and include well-known industry names (such as Siemens Gamesa, Siemens Energy, EEW or Schaeffler) as well as small and medium-sized companies.

However, past changes in the regulatory framework (starting with a cutback of the feed-in-tariff and a reduction of the 2020 targets from 10 to 6.5 GW in 2014) have had effects on the industry that many market participants describe as "disruptive". Reduced development activities as well as delays in commissioned projects have led to little or no new deployment in 2021 and 2022; resulting market insecurities and increasing cost pressure have caused some companies to either switch their focus to other activities (e.g. onshore wind), relocate to other countries or go out of business altogether. As a result, OSW employment in Germany decreased by 3,000 full-time equivalents between 2018 and 2020 and overall turnover (including exports) in the OSW sector shrank from 9.8 to 7.4 billion EUR (wind:research 2022). Manufacturing facilities that closed/ went bankrupt in Germany in recent years include PowerBlades in Bremerhaven, Adwen Blades in Stade, Nordex in Rostock (blades), Ambau GmbH in Cuxhaven (towers and foundations) and STRABAG Offshore Wind (gravity foundations) (HBS & IGM 2021). This also means that the German industry no longer sufficiently covers all sectors of the supply chain – in particular, there is a lack of companies in tower and platform manufacturing as well as installation logistics and maritime industries (wind:research 2022).

Thus, while there is significant technical and procedural experience and strong R&D in the German OSW sector, many observers and interviewees describe the situation of the offshore wind industry as having arrived at a "crossroad". Given the long project cycles in the sector, the share of highly specialized manufacturers and the existing competition with other customers along the supply chain, the single most important issue to almost all of the stakeholders interviewed was security of investment and a stable a reliable regulatory and legal framework. An example that was mentioned several times in the interviews was that the time lag between investment decisions for capacity expansion of production facilities and actually winning the orders/installation of the OSW parks causes uncertainties in the market.

In this regard, the recently announced increased deployment targets and reformed tendering procedures (signed into law in June 2022) are cautiously welcomed by most market participants, while some remain skeptical based on past experiences.

This point seems even more valid as general circumstances – in part caused or accelerated by Russia's war on Ukraine – hold a high degree of uncertainty for investors. This includes relatively low return of investment predictions (high prices and supply chain cuts), unpredictable price fluctuations in commodity markets, overall inflation, energy prices and a still tight project pipeline.

Against this background, increased targets and commitment in European countries, but also in the US could provide additional opportunities for the sector.

3.1.2 Manufacturing capabilities

Table 7 Selected operational component manufacturing facilities in Germany

Component types	Company	Location
Nacelle assembly	Siemens Gamesa Renewable Energy	Cuxhaven, Niedersachsen
Rotor hubs, frames, casings	Nordmark	Cuxhaven, Niedersachsen
Monopiles, transition pieces, jacket components	EEW SPC	Rostock, Mecklenburg-Vorpommern
Monopiles, transition pieces	Steelwind Nordenham	Nordenham, Niedersachsen
Export cables	NKT	Köln, Nordrhein-Westfalen
Control, IT and HVDC transmission technology	Siemens Energy	Erlangen, Bayern
Cable and interconnection systems	PFISTERER	Winterbach, Baden-Württemberg
Cables	U.I. Lapp Kabel	Stuttgart, Baden-Württemberg
Bearings	Schaeffler Technologies	Schweinfurt, Bayern
Bearings, drives, gearboxes, etc.	Liebherr	Biberach an der Riß, Baden Württemberg
Large steel plates (for foundations and towers)	Dillinger Hüttenwerke	Dillingen/Saar, Saarland
Rotor blade coating, etc.	Bergolin	Osterholz-Scharmbeck, Niedersachsen
Carbon, current connectors	Schunk Group	Heuchelheim, NRW
Foundation anchors, threaded rods, bolts, screws	Graewe	Finnentrop-Weringhausen, NRW

Sources: wind:research 2022; Windfair.net n.d.; IWR 2022; Siemens Gamesa RE 14.01.2022; EEW Group n.d.; Siemens Energy 27.09.2022.

3.1.3 Supply Chain Example: Borkum Riffgrund 3 (913 MW)

The following project is meant to exemplify technologies and components typically used in a contemporary offshore wind farm in German waters. Borkum Riffgrund 3 is developed by Ørsted and encompasses three previously independently named projects in close geographic proximity (Borkum Riffgrund West 1 (420 MW), Borkum Riffgrund West 2 (240 MW) and Northern Energy OWP West (240 MW)) in the German North Sea. The sites now forming Borkum Riffgrund 3 were won by Ørsted in auctions in 2017 and 2018 with 0-ct-bids (meaning the developer completely eschewed government subsidies).

The final investment decision was taken in 2021, construction is planned to start in 2023, and completion/ grid connection is expected for 2025. The project's overall capacity of 900 MW will be covered by 83 turbines of the 11-MW class (Siemens Gamesa, SG 11.0-200DD), monopiles foundations delivered by Steelwind Nordenham; and PPAs concluded with Covestro, Amazon, BASF, REWE Group, and Google (Ørsted n.d.)

The wind farm will be grid connected using a new 66kV direct connection concept between the wind farm arrays and Tennet's offshore converter platform DolWin5 (planned to be operational by 2024), eliminating the need to install offshore substations and 155kV cabling between the substation and converter platform (4C Offshore 2022b).

3.1.4 Port infrastructure and vessels

Ports

Germany has several ports at the North and Baltic Sea with relevance for the offshore wind sector. Cuxhaven, Wilhelmshaven and Bremerhaven are the main German ports for assembly, production, installation and retrofitting as well as handling and transport of offshore wind components. Additionally, the ports of Emden, Brunsbüttel, Stade and Brake are having activities in storage, handling, shipping. Apart from that, operation and maintenance are done from many smaller ports with close proximity to the offshore wind farms, such as Heligoland, Norddeich, Borkum, Büsum, Rostock and Sassnitz (Ørsted 14.05.2022). However, most components for OSW farms in Germany were delivered and installed via the Dutch port of Eemshaven and Danish port of Esbjerg due to their high capacities, local manufacturing of OEMs, and close proximity to the offshore sites in German waters.

Germany's ports are owned by the German states (similar to the public ownership of ports ("landlord model") in most parts of Northern Europe). The basic port infrastructure, e.g., piers and attached economic development areas, is developed by state-owned enterprises and then leased via Europe-wide tenders and often long-term contracts to private port operators (tenants), which invest in cranes etc.

Many experts agree that Germany's ports for offshore wind energy development need to be expanded significantly (especially in the field of installation, assembly and handling) (or other use forms of port areas need to decrease) to be able to reach the deployment targets and ensure local value creation as part of the energy transition. The offshore wind sector will not only have to compete more for port infrastructures and areas with the container business, but also with the likely growing import (and export) activities for other renewable energy technologies, such as onshore wind. There is already a significant demand for port areas to import onshore wind components.

However, multiple German ports have the potential for offshore wind related expansions:

Cuxhaven is currently the main port for OSW development and has been active in the construction and supply of offshore wind farms since 2007. Since 2018, Siemens Gamesa assembles offshore wind turbine nacelles at the port (currently SG 11.0-200 DD), which are then shipped to the offshore wind farm. Cuxhaven's offshore port has a current capacity of six berths, two of them for jack-up vessels, and is planned to be increased by a 40-hectare expansion project for offshore wind development by 2025 (incl. five to seven new berths and 1.257m quay wall) that already received construction permits. Overall, the port has the potential to increase its capacity by three terminals (Ørsted 14.05.2022). The standard way of financing the project through the State of Lower Saxony is not (fully) possible due to financial bottlenecks of the state budget and high development costs. Therefore, Cuxhaven has asked private investors, but the expressions of interest were low (since investors have high return expectations). A subsequent proposal for project funding through the federal government, the State of Lower Saxony and private investors by one-third each is still under consideration.

Bremerhaven served in the past as a port for turbine manufacturing (e.g. Senvion), shipping, installation and for laying submarine cables. However, over the last years, most offshore wind companies had to close for economic reasons and as a result of that, in 2021, the planned Offshore Terminal Bremerhaven (OTB) was stopped by Bremen's Higher Administrative Court due to the now lacking necessity of the project. The OTB development for the outer port was necessary so that the increasingly larger installation and others ships do not have to pass through the floodgates into the port, which are limited in size.

The OTB project could provide around 25 hectares of port space for the pre-assembly, storage and handling of wind turbines, a 500m-quay wall for up to three installation ships, and 200 hectares of commercial space for manufacturing companies to locate there, which would be enough capacity for approx. two wind farms per year, i.e. circa 1.5 GW (Ørsted 14.05.2022). Experts believe that an approval and construction of the OTB project, which would be theoretically possible by the end of 2024 in the best case, could substantially alleviate Germany's port infrastructure bottlenecks for OSW. Currently, the Senate of Bremen has lodged an appeal, and now the Federal Administrative Court must decide whether a legal recourse via the next higher instance is possible or not. This came after the Renewable Energy Law was changed in 2022 with the addition that now "the construction and operation (of renewable energy plants) and associated ancillary facilities are in the paramount public interest and serve public security" (EEG 2022, § 2). Whether port infrastructure is considered "associated ancillary facilities" is not (yet) clear, but if so, then this new legal framing could make positive court decisions regarding offshore wind port developments more likely.

With a view to the future offshore business, the city of Bremerhaven is also trying to develop a center for offshore wind dismantling and recycling, but there is currently still a lack of local support (in part for image reasons) for this undertaking.

Wilhelmshaven's Jade-Weser Port is the only German deep-water port that can serve ships with drafts of up to 20 meters and the country's main port for container shipping, but also plays a role in offshore (and onshore) wind development. The universal port includes an offshore service port and has areas for the assembly and handling of OWTs, areas available for commercial development at short notice, and the possibility of expanding port facilities and even building additional terminals for offshore wind development. Apart from that, also the ports of Emden, Brake, Stade, Rendsburg/Osterrönfeld, and Brunsbüttel that currently play a smaller role for the sector, have the potential to increase their infrastructure and area for offshore wind development (Ørsted 14.05.2022).

In addition to port expansion, German ports could also look for opportunities to repurpose parts of existing port space that are used for container storage but not for their active handling, for the OSW sector instead. Some experts argue that there is overcapacity in many parts of Europe for container shipping, as handling volumes are no longer achieved, which could now be used for the offshore (and onshore) wind sector, if the current tenants of these areas agree.

Vessels

According to the experts interviewed it is generally assumed that installation vessel supply will be a worldwide bottleneck in the years to come. As Asian shipyards will likely be busy meeting local and international demand, local production in Europe may gain new significance – currently, shipbuilding for the OSW sector barely takes place in Germany or Europe (the exception being Norway).

Potentially, OSW vessel manufacturing could become a good business case for German shipyards (also in the context of climate-neutral shipping and installation becoming increasingly important), but this would require a strong political backing and structural support.

3.1.5 Workforce

According to official estimates, 21,700 people were employed in the offshore wind sector in Germany in 2021, down from a peak of 29,800 in 2016 (BMWK 2022b). With around 4,000, the populous states of North-Rhine Westphalia and Baden-Württemberg are regional leaders, followed by Bavaria, Lower Saxony and Hamburg (between 2,000 – 3,000 each) (wind:research 2022).

No detailed data is available for the qualification of specialists in the sector, but it is clear that qualified specialists on different levels and with different backgrounds are required both for project development and for the construction and operation of offshore wind farms. This includes positions that typically require higher education (technical engineers, installation managers, economists, project engineers, geophysicists etc.), but also blue-collar jobs (technicians, mechatronics, electricians etc.) which also require perennial formal training in Germany. The range of professions and qualifications becomes even wider when suppliers and service providers along the value chain are considered.

While experts see Germany's high level of professional training, general competence in educational institutions and relatively large base of skilled personnel due to its offshore history as an asset, there is no denying that skilled labor shortage will be one of the key challenges for the sector.

Already today, German companies regularly name **labor shortage** as one of the major problems for the development of their business. In fact, the German economy is reporting record levels of labor shortage: In March 2022, the regular monitoring by the KOFA agency showed 558,000 open positions could not be adequately filled, which is roughly every second job offered (Hickmann and Malin 2022). 44,5 % of companies in the manufacturing sector say they lack qualified personnel – this number is even higher for industry branches associated with offshore wind, such as metal processing (57%) or electrical components (48,1%) (ifo Institut 02.08.2022). One example how labor shortages directly affect offshore wind even today was brought up by one of the interviewees, who mentioned that currently 250 positions for service engineers (on- and offshore) remain vacant, forcing a standstill of some turbines. The projected need for about 10,000 additional staff in order to reach 30 GW by 2030 will exacerbate the problem even further (wind:research 2022).

As stated above, skilled labor shortage is a general problem for the German economy (and internationally) and not specific to the offshore wind sector. For a lot of positions which primarily require solid general training (e.g. in engineering and management) this means that the offshore wind industry is competing with other sectors that likely also suffer from labor shortage. In addition, working conditions in positions requiring physical presence at the offshore wind sites (especially in installation, maintenance and servicing) seem to be seen as increasingly unattractive despite high wages. The fact that companies in the wind energy sector (including onshore) have been providing below-average professional training rates compared to other sectors (HBS & IGM 2021) is also part of the picture and has led the federal government to make training quota one of the qualitative criteria for future site auctions.

While this point applies to the very broad field of professional training in general, there are very few training programs that focus on the specifics of offshore wind, where specialized knowledge is usually acquired on the job. In contrast, there is quite a number of institutions offering trainings according to GWO standards.

3.1.6 Converter platforms and grid connection

Germany currently has no manufacturing capacities for new large **offshore converter platforms** and only four converter platforms for offshore wind farms were manufactured by Germany's shipyards in the past (between 2010 and 2017). Offshore converter platforms for Germany's OSW farms are being built mainly in Asia (on the Arabian Peninsula, in Singapore or Indonesia) and then towed to the German North Sea and Baltic Sea. For example, the large converter platform for the grid connection of Nordsee One, Gode Wind I und Gode Wind II was manufactured in Dubai, transported from there to a shipyard in Norway for installation preparation, and then brought to Germany and installed by Swiss company ABB Power Systems as contracted by Tennet (IWR 2015).

Also, the construction of the Borwin 6 converter platform for the grid connection of several offshore wind farms off the North Sea island of Borkum (by 2027) was recently awarded by the grid operator Tennet to overseas suppliers: the US company McDermott is responsible for platform construction, and two subsidiaries of the Chinese state-owned corporation SGCC are producing the electrical equipment and computer technology.

There is an ongoing debate in Germany, whether relying on Chinese suppliers for converter platforms' electrical equipment should be a concern or not: Some argue that those platforms can be surveyed, intentionally overloaded or shut down and should therefore be covered by the IT security laws, which were recently tightened to protect the 5G network from Chinese equipment suppliers. Others deem this less of a problem since those converter platforms would only be supplied but not be operated by Chinese companies. As part of the latest amendment to the Wind Energy at Sea Act from summer 2022, the possibility was introduced, to exclude "non-EU" bidders from the tenders, if this is in the public interest (so-called "China clause").

Offshore grid connections are provided by the relevant TSOs in Germany, Tennet for the North Sea and 50hertz for the Baltic Sea. This means that project developers will not have to bear the cost of the connection (nor take care of the realization), but it requires upfront coordination and may reduce the flexibility in the design of wind farms in some cases.

TSOs are thus involved in the planning process and responsible for timely finalization of connections. They usually do so by way of tendering – according to recent reports there is a tendency of tendering higher volumes at once to provide certainty to suppliers (Handelsblatt 23.06.2022), but probably also to secure the suppliers' capacities.

In terms of technology, the standard procedure over the last years in Germany was to route electricity (AC) from the turbines to offshore substations, transform voltage to 155 kV (AC), and then route it to the converter platform with a power transmission capacity of usually between 0,4 and 0,9 MW, where it would be transformed to high-voltage direct current (HVDC) of 150 to 320 kV (DC) and connected to the mainland via HVDC subsea cables (Tennet n.d.).

Newer solutions connect the wind farms directly (via 66 kV) to the increasingly larger converter platforms with up to 2 GW of transmission capacity (no intercalated offshore substations and 155 kV inter-array cabling needed) and transform it to 525 kV (DC) for the mainland connection, which increases the total interconnection capacity and decreases overall system costs. Tennet plans to use the new 2-GW class interconnection systems to connect wind farms in Germany (North Sea) and the Netherlands from 2028 to 2031 (Tennet n.d.).

3.2 Outlook on supply chain vulnerabilities, gaps, and 2030 targets

As indicated above, Germany is no longer able to cover the whole supply chain with domestic manufacturing. While reliance on international tier 2 and 3 suppliers (e.g. for sensor technologies, semiconductors, rare earths) is not entirely new, this now also includes crucial tier 1 products, such as:

- Blade manufacturing (no facilities anymore after the announced closing of the Nordex facility in Rostock (from June 2022).
- Converter platform manufacturing (last possible site threatened due to recent insolvency of MV Werften).
- Installation vessel supply and shipbuilding.
- Jacket and floating foundations.

With a massive upswing expected internationally for the offshore wind sector, there are thoughts of (re-)establishing businesses in some of the fields named above. For example, as the **demand for converter platforms** is expected to rise sharply in the coming years and Germany alone would need a significant number of them until 2030, there are discussions about a **revival of manufacturing capacities** in Germany. According to observers, the shipyard site of insolvent MV Werften in Rostock-Warnemünde would be one of only two shipyards in Europe (together with Cadiz, Spain) capable of building the large new converter platforms class used for offshore wind farms in the coming years. This could potentially offer the opportunity to re-develop a future market and simultaneously complement the OSW value chain and link it with the value chain of the shipbuilding industry, thereby creating additional value added and employment in two sectors of the economy that are crucial for the coast (HBS & IGM 2021).

This coincides with **expected bottlenecks** along the international supply chain. **Converter platforms** were explicitly mentioned by some of the experts interviewed due to limited existing capacities, particularly demanding profiles for specialists and long investment cycles. Another issue frequently mentioned were **vessels**, particularly installation vessels, the (lack of) capacity for manufacturing in Germany in combination with expected decreases in import and leasing possibilities. **Port infrastructure** and the respective equipment for increasingly larger facilities (e.g. heavy-duty quays, crane capacities) are seen as a problem especially since sites in Europe are limited and the “stationary” services required cannot be replaced by imports. Other areas mentioned where global shortages are expected in the short and medium term are OSW components, especially **towers** and **foundations**.

For some suppliers, a global shortage of **semiconductors** and chips (due to pandemic-related supply chain cuts) and high dependence on Chinese/ Asian exports of key rare earths, semiconductors and chips is potentially challenging.

Interviewees were generally rather optimistic with regard to **turbines, cables** and certain raw materials such as **steel.**

However, the expected supply chain constraints in combination with limited port infrastructure, permitting times and increasing international competition for OSW manufacturing due to high deployment targets in many countries still led many interviewed specialists to believe that the **30-by-30 target in Germany** – while theoretically "doable" – will likely not be achievable in time in practice. This assessment is also backed up by wind:research, who found that based on their climate protection scenario the current supply chain would not be strong enough to meet the needs of a rapid OSW buildout similar to the newest goals of the German federal government (wind:research 2022) and it will be hard to increase or replace capacities in the near term.

That said, market participants are by no means critical of the deployment goals or overly pessimistic with regard to the future development of the offshore wind industry in general. Many interviewees have stated that the challenge is more in the timeframe than the capability of the market players to adopt to changing conditions. A **clear and reliable framework** and a **coherent approach** (in some cases possibly including government support) for developing the industry were among the most wished for components to provide the **security of investment** that is needed to take investment decisions at developer level that would then trickle down to all participants of the supply chain. As stated earlier, this does not necessarily refer to a given policy framework, but partially reflects a general wish for long-term stability in the light of changing political priorities.

4 Policy recommendations and collaboration opportunities

4.1 Regulatory framework adjustments

Policy recommendations:

- The most important aspect for the entire OSW industry in Germany and USA is to create a stable and reliable framework for OSW expansion, including well-established short-, medium-, and long-term goals, bidding procedures, and support mechanisms, as well as facilitated, accelerated, and legally secure permitting processes for OSW parks, component production sites, and infrastructure. Based on such conditions, many experts believe that the market would be able to provide the necessary capacity in most of the supply chains as trust of investors is (re)built.
- Permitting processes for OSW farms, manufacturing capacities and ports should be facilitated, e.g., by streamlining and bundling of approval and appeals procedures (similarly to the process recently applied for LNG in Germany)[7], ensuring sufficient staffing of relevant agencies, and defining offshore wind infrastructure as in the paramount public interest and serve public security (as recently done through changes to Germany's Renewable Energy Law, EEG).
- Differences in regulations, standards and norms for the OSW sector exist between the US and Germany (as well as internationally), e.g. technical and safety standards for the design, manufacturing, installation, operation and interconnection of OWTs, which could be harmonized as much as possible in to be distinguished aspects to reduce market entry barriers and ensure efficient and cost-effective supply chains. Companies are currently often lacking knowledge about the framework conditions in foreign markets, which is seen as a disincentive to offshore wind supply chain expansions. (In contrast to that, German/ European companies/ experts with existing business and experience in the US onshore wind and solar PV market do already have the knowledge about the market specifics and are thus in an advantageous position as far as offshore market entry is concerned.)
- For Germany/ Europe: Strengthen cooperation and harmonization within the EU/ Europe on offshore wind regulations (especially on grid connection rules, market integration, standardization, etc.) to enable the build-up of joint offshore interconnection and energy storage projects.
- For the US: Inflation Reduction Act provisions connecting offshore wind lease sales to offshore oil and gas lease sales should be implemented in a way that they don't slow down or hinder OSW deployment. Sufficient staffing in agencies and coordination is therefore necessary.

Collaboration opportunities:

- Knowledge and best-practice exchange on securely implementing offshore wind deployment targets, organizing auctions and grid connection projects in a timely and

[7] To ensure Germany's energy supply in the wake of Russia's war against Ukraine, an "LNG Acceleration Act" (LNGG) was passed in May 2022. Stating "overriding public interest" and national security interests, the law allows for simplified permitting procedures for LNG terminals e.g. by shortening periods for public comments and objections and allowing for exemptions from environmental impact assessment under certain circumstances. (For more details see TaylorWessing, 10.6.2022)

coordinated manner, and financial support mechanisms for OSW electricity generation (e.g., through workshops, research papers).

- Knowledge and best-practice exchange on accelerating and facilitating permitting procedures as well as developing sufficient staffing for relevant administrative institutions (e.g., through workshops, study tours).
- Workshops on differing regulations, norms and standards relevant for the OSW sector and discussion about the necessity/potential for harmonization.

4.2 Workforce

Policy recommendations:

- The challenges with regard to skilled labor shortage in the US and Germany are twofold. Firstly, companies along the OSW supply chains compete with other industry branches for skilled workers in all areas including project development (engineers, project managers) and blue-collar workers (electricians, mechanics, service technicians). This general trend is expected to intensify in the next few years. On top of that, the offshore industry faces challenges especially in construction and maintenance due to working times and conditions offshore. Therefore, many interviewed experts see the urgent need for a strong training and qualification campaign to increase the interest of workers for the sector and at the same time expand training/ retraining programs. Additionally, more attractive working time conditions could be developed with all stakeholders especially for the offshore jobs, e.g. through the development of a specific labor market strategy.
- There is a need to develop/expand workforce training (and re-training) programs in the US and Europe/ Germany to serve the need for the planned capacity expansions. US institutions in this field could benefit from European experiences over the last decades; European stakeholders may learn from successful current approaches in the US regarding the targeted and accelerated training of personnel for new manufacturing facilities together with educational institutions.

Collaboration opportunities:

- Best-practice exchange and potential cooperation on (re-)training programs and potential harmonization of training standards within the offshore wind sector, e.g., through facilitating transatlantic collaborations between educational and training organizations (colleges, universities, labor unions etc.) to enhance training curricula; potentially harmonize requirements for mutual recognition of qualifications, make jobs more attractive (e.g., through bilateral programs).
- Development of joint re-training programs for workers from fossil fuels with existing experiences in related energy technologies industries (e.g., from the Gulf of Mexico region) to strengthen the OSW workforce and ensure a just transition.

4.3 Supply chain capacity build-up and local content requirements

Policy recommendations:

- For the US: Several experts argue that the different and competing local, regional and national content requirements for the supply of offshore wind components as part of state level renewable energy procurements (and BOEM lease sales) may lead to inefficient OSW supply chains, overcapacities and potentially stranded assets in the medium and long term, and as a result to high project and electricity generation costs. Furthermore, the different requirements bring unnecessarily high market complexities and may thus make investments in US manufacturing sites less attractive compared to other markets (especially for foreign companies). Therefore, experts suggest that local and regional content requirements should be coordinated within the relevant stakeholders and, as a possible compromise, only national requirements should be imposed (and a common offshore wind strategy developed).
- For the US: Financing of offshore wind projects is often still more challenging in the US than in Europe, since developers have problems to find US private investors due to difficult risk assessments and high-risk premiums. The US market here relies to a large extent on European banks and law firms. In Europe/ Germany, more advanced risk assessments for offshore wind projects lead to investment decisions even from conservative pension funds and it might well be worth exploring the systemic differences.
- For Germany/ Europe: Supply chain bottlenecks and gaps need to be analyzed more detailed and, together with the industry, strategies should be developed to address them. As part of that, it should be analyzed where government support through funding/ financing for expansion/ development of OSW manufacturing capacities would be necessary to overcome existing investment insecurities in the market. Suppliers could, for example, receive government guarantees for urgently needed investment decisions through the KfW if its offshore wind program (KfW-Produkt Offshore-Windenergie) would not apply to OSW farm developers only.
- For Germany: Some experts call for the implementation of some national/ regional content requirements in Germany as well, but harmonized with other countries in the EU, in order to incentivize supply chain development and job creation in Germany/ the EU and protect the domestic industry. They argue that the recent changes to the Wind Energy at Sea Act with soft national content criteria will most likely not be effective enough and thus the observed outsourcing processes in manufacturing to lower cost countries by OSW OEMs and suppliers will likely continue. In addition, the new criterion regarding renewable energy use is seen as too unspecific, complicated and leaving room for greenwashing (e.g., by suppliers from Asia), and the training criterion is hardly realizable because it is much too complex and directed towards the unforeseeable future.

Collaboration opportunities:

- Utilize/ adapt the existing stakeholder platforms (online) for knowledge sharing on available OSW experts on both sides (e.g., for maritime co-use, workforce development, grid connections, market entry and regulations) and active connecting of interested parties to facilitate the needed supply chain (re-) developments. Arguably, a comprehensive and detailed online platform could be helpful for these aspects, since finding the right expertise can be challenging.

- Knowledge exchange on the effects of local content requirements on supply chain developments and how to potentially better coordinate them.
- Knowledge exchange about OSW investments and financing options between US and German/ European stakeholders.
- Facilitate direct exchange between market participants in both countries, using existing platforms (IPF, WindEnergy Hamburg, fact finding missions, German Offshore Wind Initiative, GACC presentations etc.).

4.4 Multilevel stakeholder cooperation and strategy development

Policy recommendations:

- Many interviewed experts argued that there is a lack of cooperation and coordination on offshore wind deployment and infrastructure development both between the states themselves and between the states and the federal government in the US and (to a lesser extent) in Germany. Relevant activities could be e.g., the development of a national offshore wind strategy (similar to the H2 strategy in Germany) that includes policy harmonization to avoid fragmented state-specific policies and leverage synergies (esp. for the US), coordination of manufacturing and port infrastructure expansions (esp. for Germany), overall interconnection planning (for the US), and development of strategic centers for certain locations/ ports (e.g., decommissioning and recycling). Such cooperation and coordination activities between different stakeholders were so far barely done successfully in Germany and the US, but experts and experiences in other countries (e.g. the Netherlands) point to its importance. It could ensure efficient and stable supply chain buildout and OSW project costs.
- For the US, the new "Federal-State Offshore Wind Implementation Partnership" launched in June 2022, as "a first-of-its-kind forum for collaboration between federal and state officials to accelerate offshore wind progress" (The White House 2022b), should be strengthened.
- Governments should also facilitate dialogue between different and often competing users of maritime space, such as fisheries, shipping companies, the military, conservationists and the offshore wind industry to find compromises, synergies and develop co-use options for these areas. More stakeholder cooperation outside of the official marine spatial planning processes can prevent appeals and long-lasting lawsuits against certain offshore wind projects.

Collaboration opportunities:

- Knowledge exchange (also with third countries) on establishing successful cooperation and coordination processes between different, partly competing offshore wind stakeholders (that could potentially lead to developing overarching offshore wind strategies) (e.g., through workshops, studies).
- Best-practice exchange on good collaborations between unions and OSW companies in the US (and Germany).
- Knowledge exchange and experience presentation on maritime co-use options and potential positive synergies resulting from it (e.g., positive effects of offshore wind farms on fish resources). In the US, multiple studies on this topic exist, but these are criticized by some for being only done on the small OSW farms available and over short period of time.

Therefore, bringing together stakeholders, such as fisherman from the US and Germany/ Europe, and providing a platform for sharing experiences on a working level could have the potential to enhance understanding in this field.

- Establish joint RD&D projects on maritime co-use and synergies.

4.5 Ports, vessels and interconnection infrastructure

Policy recommendations:

- For Germany: There is currently a lack of private interest and investment securities for the financing of OSW port projects mostly due to the negative development of the sector over the last years. Therefore, OEMs and OSW developers often refrain from committing themselves to long-term supply contracts with ports (and local suppliers) in Europe, which would be necessary for large investment in the necessary port infrastructure and connected OSW manufacturing capacities. Based on that, many experts believe that the federal government should consider to participate directly in the financing of offshore wind port infrastructure critical for the energy transition in Germany. However, to make this possible, the states would have to agree and a stronger cooperation between them and the federal government would be needed. The ongoing successful cooperation process for funding, permitting and construction of floating LNG import terminals could serve as an example for the necessary port expansions to reach the OSW deployment targets and strengthen the local value chain. Apart from direct financing of projects, also other forms of support for port infrastructure development can be considered, such as Contracts for Difference (CfDs) for offshore wind ports and EU funding. Apart from the expansion of existing ports, additional offshore wind development areas in ports can also be achieved by encouraging tenants of container storage areas in ports to pass on parts of their (over)capacities towards the offshore wind sector. For this, public and private stakeholder should start to work together to find suitable solutions. Also, better cooperation and dialogue within European countries on port development and funding would be beneficial, since there is likely potential to learn from successful OSW ports in other countries, such as Esbjerg (DK), but an institutionalized dialogue format regarding to this does not seem to have been established yet.
- For Germany: The construction of offshore wind converter platforms is a critical element for reaching the deployment goals. However, Germany is currently lacking the necessary shipyards capacities for this. Therefore, experts argue that the federal government should consider supporting the insolvent MV Werften in Rostock-Warnemünde and the new proposal by the Smulders group (BEL) to manufacture converter platform production there, since it is one of only two shipyards in Europe (together with Cadiz, Spain) capable of building the new large 2-GW converter platform class planned for the end of this decade. This would offer the opportunity to re-develop a part of the OSW supply chain and simultaneously link it with the value chain of the shipbuilding industry, which is also crucial for the economy at the coast.
- For the US: The current complex planning and coordination processes for OSW grid connection development at the state, federal and utility levels should be streamlined and accelerated, since they pose a large challenge for the necessary shared transmission development offshore and onshore with respect to system integration and required grid upgrades. Additionally, experts argue that changing the current US system (of connecting every project individually by AC export cables) should be considered, since it would not be technically feasible in the long-term and shared transmission development could reduce

costs, environmental impacts, and improve reliability. For that, an overarching strategy and institution would be necessary for coordination of the interconnection of OSW farms and the grid buildout onshore. In Germany, for example, the interconnection comes with the tendering of sites and was so far basically free for the developer.

- For the US: the Jones Act requiring certain vessels for the OSW sector to be manufactured in the US and US-flagged in order to operate from US ports is seen by many experts as an issue requiring careful consideration to ensure rapid offshore wind build-up. While some Jones Act-compliant strategies for using existing non-US-flagged vessels were found and new domestic vessel manufacturing capacities are being developed, more clarity about the application of specific regulatory requirements would help the industry to come up with workable solutions.

Collaboration opportunities:

- Knowledge and best-practice exchange (with third countries, e.g. the Netherlands and Denmark) on how to incentivize/ support the necessary expansion of offshore wind ports and what coastal cities can do to support the development of local OSW industry.
- Knowledge and best-practice exchange how to best organize, coordinate and support the interconnection of OSW farms to the grid and the necessary onshore grid buildout.
- Dialogue on current consequences of the Jones Act requirements for the offshore wind buildout and European supplier companies.

4.6 Cooperation on rare earths, recycling, and green materials

Policy recommendations:

- The permanent magnet generators currently used in offshore wind turbines are mostly based on rare earths (especially terbium and neodymium), which are mainly supplied by China. Therefore, many experts argue that diversifying rare earths supply chains, developing alternative, less rare earth-intensive technologies (such as novel superconducting wind generator designs), as well as recycling processes will be crucial in the US and Germany/ Europe in order to reduce the dependence of such imports from just one supplier country. The global demand for rare earth elements in wind turbines will increase substantially until 2050 (European Commission 2020), while increasing the "production of specific elements is challenging because rare earths are typically found blended together in low concentrations and require extensive processing to concentrate and separate the individual elements". Recycling of rare earth elements is currently not done commercially, but "ongoing research and commercial start-ups are investigating several potential processes" (Baranowski et al. 2022).
- While some OWT components can be recycled, e.g., steel, metals, concrete, electronics components, some have currently only "limited recycling options, e.g., fiberglass/ carbon fiber" used for blades, and others, such as rare earth elements, are not typically recycled today. "New facilities and processes are under development with the aim of lowering the cost and increasing the volume of recycling for materials" (Baranowski et al. 2022). Fiber-reinforced composites represent the "largest fraction of material that is not readily recyclable", since this is technically difficult and not always economical (Baranowski et al. 2022). However, "mechanical, thermal, and chemical recycling processes have been demonstrated in laboratories and are at various stages of scaling up to commercial

implementation” (Baranowski et al. 2022). The OEMs Vestas, GE and Siemens Gamesa have announced efforts to increase recycling of wind turbine blades. DOE’s NREL works on two projects to enable wind turbine recycling based on alternative technology use and DOE funds a recycling and reuse project for fiberglass (Baranowski et al. 2022; Vestas 2022; GE 08.12.2020; Siemens Gamesa 07.09.2021).

- Recycling has not been sufficiently considered in Germany/ Europe to date, and is only now gaining attention as the first OFTs will be taken off the grid in the next few years. The company, Neocomp in Bremen is so far the only recycler in Germany specializing in rotor blades, which shreds them into fiber and fuel for the cement industry (Neocomp n.d.). Furthermore, RWE tests the world’s first recyclable blade at its offshore wind farm Kaskasi in Germany and Fraunhofer IWES runs R&D activities in Bremerhaven for recyclable rotor blades (RWE 07.09.2021; Fraunhofer IWES 06.04.2022).
- Recycling options for OWTs should be considered in the design of OSW farms, ports and manufacturing. Special logistics are needed for decommissioning and recycling processes. Governments should actively support the development of strategies and economic centers for these parts of supply chain.
- Steel makes up the large majority of material input and weight of an OWT, but current steel production processes are very emissions intensive. Therefore, the development of green steel for offshore wind turbines is necessary to further lower the emissions footprint of the generation technology. First project outlines are being developed in Germany to use offshore wind energy to produce green hydrogen and renewable electricity, which are then used for green steel production for OWTs. Apart from green steel for OWTs, also the topic of hydrogen powered OSW vessels is gaining attention. The governments should consider supporting these developments (and potentially mandating their gradual use at some point in the future).

Collaboration opportunities:

- Establish joint RD&D projects to accelerate the efforts towards diversification of rare earths supply chains and the developing alternative technologies.
- Best-practice exchange and RD&D collaboration on recycling options and strategies for offshore wind components incl. decommissioning.
- Knowledge exchange and potentially establishment of joint RD&D project on green steel production for offshore wind energy.

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