Standardization of Turbine Design and Installation Vessels to Accelerate the Offshore Wind Industry in the United States

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Keywords: science diplomacy; sustainable energy; offshore wind; wind turbines; installation vessels

Executive Summary: Offshore wind energy has gained attention as a promising renewable energy source with many benefits, including clean, sustainable, and scalable electricity production. Despite the vast potential for offshore wind production in the United States, the country lags in its development. The industry struggles with supply chain challenges related to the complex logistics around the design and construction of many component parts, installation and maintenance vessels, and shipyards that can accommodate the massive turbine components before installation. These challenges are complicated by the rapid increase in size of offshore wind turbines to achieve higher power generation, which are not easily handled by other parts of the supply chain. The US lacks access to wind turbine installation vessels (WTIVs), particularly those that can install very large turbines. To address these issues, we propose policy options to the US Bureau of Ocean Energy Management of the Department of Interior and the US Department of Energy to spearhead standardization in this sector of the economy by exploring standardization of maximum turbine size, investment in WTIVs, or allowance of unrestricted or market-driven offshore wind farm development. These options have great potential to enable growth in the offshore wind energy sector in the US and achieve the federal government's goal of 30 GW of offshore wind energy by 2030.

I. Introduction: Challenges and opportunities in the expansion of offshore wind energy

At a time when industrialized countries embrace offshore wind as a path to the green transition, the US lags behind as the sector meets serious obstacles and barriers to achieve the government targets. For example, Denmark installed the world's first offshore wind farm, Vindeby, in 1991, with a total installed capacity of 5 megawatts (MW), which covered the annual consumption of 2,200 Danish households (National Grid 2024). Today Denmark produces 46.8% of its electricity from wind and has an installed offshore wind capacity of 2.7 gigawatts (GW) (International Trade Administration 2024, Reuters 2024).

As of 2023, 10.2% of the total US energy consumption is fueled by wind energy (US Energy Information Administration 2024). However, with over 70,000 wind turbines installed with a capacity of 147.5 GW (Morey and Jell 2024), only nineteen are located offshore at three completed wind parks totalling 174 MW of energy (Hoen et al. 2024). This lags behind the US offshore wind energy target of 30 GW by 2030 to help meet greenhouse gas emissions targets (Musial et al. 2023). This discrepancy is not due to the lack of available coastline sites in the US, which has an estimated potential of generating 4,200 GW in offshore wind energy, more than three times the current US electricity demands (US Department of Energy 2023).

In the US, barriers to investment and construction of offshore wind projects include high costs of transmission infrastructure and maintenance (Powers et al. 2022), a domestic supply chain that is unprepared to support manufacturing and construction of turbines and related components, and a long permitting process (Musial et al. 2023). The passage of the Inflation Reduction Act of 2022 introduced tax credits, increased investments, and accelerated permitting processes (Musial et al. 2023). However, these policies need to be bolstered to ensure timely construction of offshore wind farms, as evidenced by recent cancellations of multiple projects along the US East Coast due to supply chain issues, high interest rates, and insufficient tax credits (Parry 2023). In this paper, we will address two primary and interconnected obstacles: (1) the lack of available specialized vessels required for offshore turbine construction and (2) the lack of standardization of turbine size.

The first challenge to the completion of offshore wind farms in the US is the lack of available specialized vessels required for construction, including wind turbine installation vessels (WTIVs). WTIVs are massive vessels capable of carrying component parts for multiple turbines, jacking the vessel above the water using temporary legs in the seafloor, and lifting, maneuvering, and installing of the turbine tower and additional parts using a heavy lift crane, all while also accounting for the ocean dynamics (Goh 2022). Currently, the US lacks WTIVs, mainly due to the high upfront cost of vessel construction, though one is under construction and is expected to be completed by 2025 (Buljan 2024, Shenk 2024). This is in comparison to Europe, which currently has sixteen WTIVs in operation (Shields et al. 2022). This lack of US-based WTIVs may necessitate the use of WTIVs from other countries, mainly from Northern Europe, which may opt to deprioritize US businesses if they can service more convenient projects in the North Sea (Musial et al. 2023). The use of non-US WTIVs is further complicated by the US Jones Act of 1920, which prohibits foreign-built vessels from moving cargo between US ports, including offshore wind farm sites in US-controlled ocean areas. For offshore wind farms to be serviced by foreign WTIVs, turbines must be transported from US ports to the permitted sites by US vessels where the foreign WTIVs complete the installation, which adds additional time and logistical hurdles (Olney 2020).

A second challenge to offshore wind farm installation is the growing size of turbines and the subsequent construction needs. In 2010, the average capacity of all existing offshore wind turbines globally was just 3 MW; however, by 2022, the average capacity more than doubled to 7.7 MW, with more increases expected in the coming years (Musial et al. 2023). This increased capacity is a result of growing turbine rotor diameters (i.e., overall turbine size), which grew from about 100 meters to 175 meters in the same time period. Larger turbines are attractive to energy companies because the larger swept area of the turbine blades can harness more energy, but they also require larger WTIVs to handle the large turbine components. This leads to accelerated obsolescence of existing, smaller WTIVs, as they are unable to be used for construction of the larger turbines. While new turbines are introduced almost every year, new WTIVs take a minimum of three to four years to build (Shields et al. 2023), and require a significant capital investment of approximately $750 million (Ferry 2024). WTIV developers have opted to build WTIVs for near-term project needs, ultimately leaving the older WTIVs unable to service new turbines after just a few years because of the growing turbine size (Goh 2022). This mismatch in the growth of turbine sizes and construction of new WTIVs is illustrated in Figure 1. Ultimately, while offshore wind farm developers may prefer larger turbines to reach higher power capacities, there is currently not a long-term pathway for their installation, particularly in the US, without sufficiently large WTIVs.

Federal policies and investment strategies can address the offshore wind industry's need for standardization around turbines and related installation infrastructure. In the US, the federal government could use the current situation to its advantage by spearheading standardization and targeted investments to achieve the US goal of 30 GW of offshore wind power by 2030. The US Bureau of Ocean Energy Management (BOEM) of the Department of Interior (DOI) and the Department of

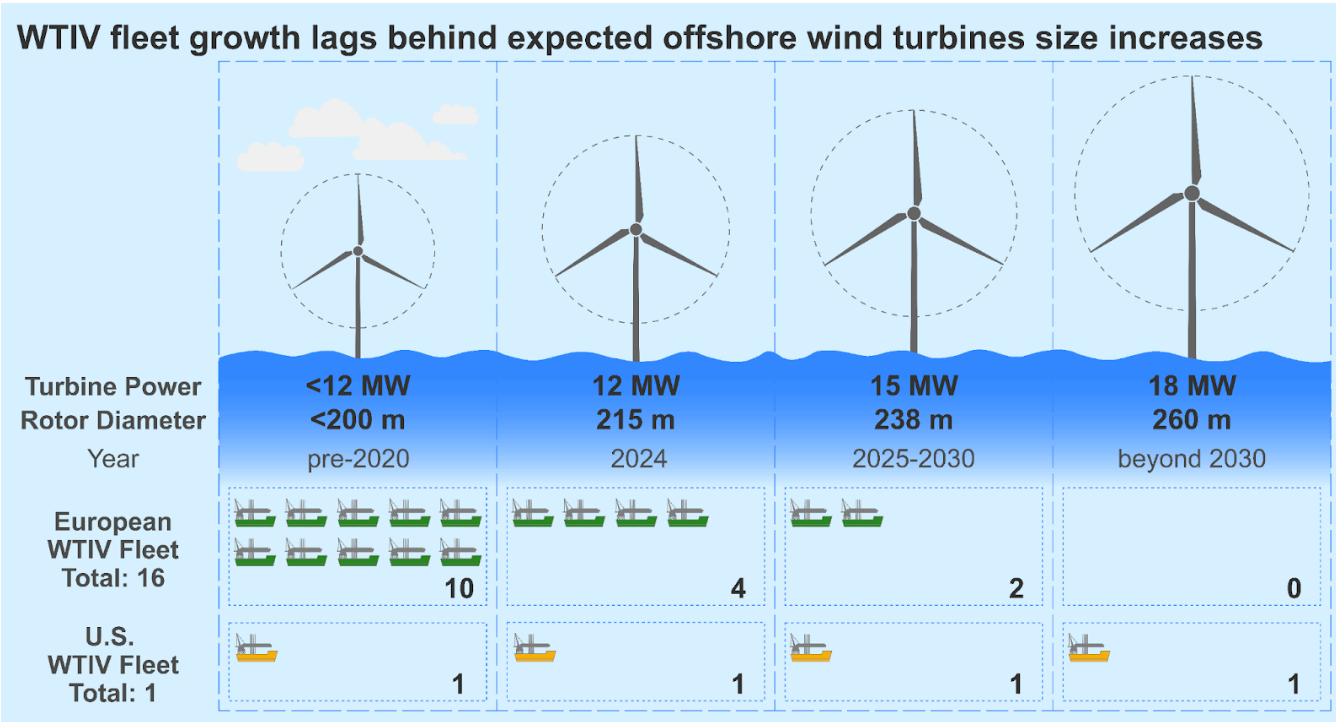

Figure 1: The increase in size of commercial offshore wind turbines is outpacing the development of compatible WTIVs. The figure shows the predicted rotor diameter for the majority of installed offshore wind turbines each year, showing the growth of the average installed turbine size. Larger and higher power turbines are brought to market every few years and existing WTIVs may not be sufficient to service the new projects. Notably, the US WTIV is the only existing WTIV expected to be able to install next generation turbines with the expected power of 18 MW (Data adapted from Shields et al. 2022).

Energy (DOE) are positioned to develop standards and incentives to streamline the construction of offshore wind farms from the supply chain to installation vessels and shipyards.

II. Policy options

i. Option 1: Government investment in new WTIV construction

The offshore wind industry relies on specialized vessels to support the installation and maintenance of each project, with WTIVs being the most important and also the most expensive. US regulations under the Jones Act restrict access to US ports by non-US WTIVs, posing an additional limitation to the streamlined installation of offshore wind turbines. Only one Jones Act compliant WTIV, to be completed by early 2025 by Dominion Energy, is under construction. Ultimately, the US lacks access to sufficient vessels to allow for the timely installation of projects to reach the 2030 targets (Musial et al. 2023). We propose that the federal government develops an incentive program to leverage investments of $6 billion to construct a fleet of four to six Jones Act compliant WTIVs, support vessels, and necessary marshaling ports by 2030 to enable the potential fulfillment of federal offshore wind targets (Shields et al. 2023).

Advantages

In the US, offshore wind farms in various stages of planning and construction have a capacity of approximately 400-2,500 MW per site and rely on individual turbines with capacities ranging between 10-15 MW (Musial et al. 2023). Installation of such an offshore wind farm is predicted to take two to three years, which could be extended by either insufficient vessels or the use of foreign WTIVs (American Clean Power 2021, Musial et al. 2023). Federal investment in the construction of WTIVs is crucial to ensure timely installation of offshore wind turbines. Additionally, government incentives encourage private investment as investors gain more confidence in the profitability of government-backed projects (Musial et al. 2023).

While European WTIVs could be used for US projects, barriers to access these vessels, such as deprioritization of non-European projects, highlight the need for US-based WTIVs that can prioritize US offshore wind developments. The construction of Jones Act compliant (i.e., US built) WTIVs promises to create job opportunities for American workers throughout the supply chain, as demonstrated by the construction of the Dominion Energy WTIV, which used 14,000 tons of US-sourced steel and over 1,200 American workers (Dominion Energy 2024). The completed vessel will ensure additional long-term jobs for Americans working on the support and maintenance of operational offshore wind turbines. The offshore wind sector is expected to add up to 58,000 jobs in offshore wind energy to the existing 120,000 full-time wind energy jobs, most of which are currently in the more mature land-based wind energy sector (Stefek 2022, Wiser 2023).

According to the National Renewable Energy Laboratory (NREL), an investment of about $6 billion would more than double the installed offshore wind farm capacity by 2030 and make the 2030 offshore wind capacity goal of 30 GW possible to achieve (Shields et al. 2023). The passage of the Inflation Reduction Act of 2022 improved the annual wind energy installation predictions (inclusive of both land and offshore wind) for 2026 from 11 GW to 18 GW (Wiser 2023). Further investment in US built WTIVs and other support vessels would provide avenues for job creation and improve US capacity to install offshore wind turbines.

Disadvantages

While the construction of Jones Act compliant WTIVs enables the timely construction of offshore wind farms in the US, construction of WTIVs involves high risks. One such risk for these projects includes the large investments required, costing more than $500 million per WTIV (Musial et al. 2023). Due to the long construction time of about five years, the return on investment might not be realized quickly. Even with adequate funding, there is always the risk of projects being canceled, as emphasized by the recently canceled offshore wind farms and contract renegotiations (Niezrecki 2024). Despite the high cost of these vessels, Jones Act compliant WTIVs are both time and cost effective for US projects. A potential alternative to building new WTIVs is using repurposed vessels; however, the added challenges of this option are predicted to double the cost, as compared to building new WTIVs (Powers et al. 2022). Additionally, WTIVs offer the flexibility of being used as assistance vehicles at oil platforms and during salvage operations.

ii. Option 2: Standardize maximum turbine size

State of the art wind turbines have grown in size from about 30 meters in diameter thirty years ago to 220 meters today. This growth has come in response to demand by offshore wind farm planners for increased power generation of individual turbines. However, manufacturers have experienced difficulties with the rapid development of new turbines, causing the suspension of multiple projects. The decision by wind turbine manufacturer GE Vernova to abandon production of an 18 MW turbine caused the cancellation of multiple offshore wind farms totalling 4 GW in the state of New York, whose proposed plans relied on large turbines to achieve the required balance of cost and power generation (Martucci 2024). GE Vernova is instead focusing on the production of a 15.5 MW turbine, still the largest made by GE Vernova, but it is not expected to be released until late 2025. Such issues demonstrate the effects that continuously changing turbine production has on timely and reliable installation of offshore wind farms.

Standardization of turbine size for a 10-year period may allow for rapid and efficient expansion of the installation vessel fleet size and development of supply chains to meet industry standards. We propose that BOEM promote standardization of maximum turbine diameter to approximately 220 meters. This standardization would enable offshore wind farm planners and industrial partners, including WTIV investors, to predict the needs for turbine and associated components, streamlining the overall production and installation process. Importantly, the proposed turbine sizes are compatible with existing WTIVs and could provide confidence in design specifications for the construction of future WTIVs.

Advantages

Standardization offers the opportunity to drive economies of scale and improve the quality, innovation, and financial outlook for the industry. Companies operating throughout the supply chain have emphasized the urgent need for standardization, specifically concerning the growing size of new turbines, to avoid serious bottlenecks in the industry (Richards 2023). The authors confirmed this through anonymized interviews with industry partners, who stated that the increasing turbine size has put installation infrastructure under massive pressure. Additionally, recent disclosures from wind turbine manufacturers have revealed financial losses due to poor testing and quality control, resulting from shortened development periods to remain competitive (Steitz and Chestney 2023). For example, in 2024, a GE Vernova Haliade-X turbine in a Massachusetts offshore wind farm experienced a blade failure, in what was categorized as a quality control oversight (DiGangi 2024).

Standardization of maximum turbine diameter would allow manufacturers to focus on the quality of existing models, while still allowing for innovation. Longer industry-wide development cycles may also encourage research and development of non-traditional turbine designs with additional benefits (Roga et al. 2022, Schubel and Crossley 2012). For example, current designs for extreme weather-proof turbines depend on shorter blades and stronger material to withstand hurricane speed winds, but could benefit from increased power generation and materials engineering advances (Rose et al. 2012; Li et al. 2022).

In addition, the rapidly increasing size of offshore wind turbines leads to unpredictable design of turbine components, which risks WTIVs becoming obsolete quickly. Development of larger turbines without a clear route to install them dissuades investment in the offshore wind industry, particularly in WTIVs. Standardization of turbine components would therefore support long lifetimes and positive return on investment for WTIVs, which require long construction times and high costs (Richards 2023). Federal and state governments granting project permits and leases, such as BOEM and DOE, could promote standards for the developers of wind farms to follow, including the turbine models and proposed sizes. A 10-year period of standardized turbine size would drive concurrent development of turbines and compatible installation vessels and shipyards, ensuring that turbines can be installed with the existing equipment.

Disadvantages

The main disadvantage of standardizing maximum turbine size is the reduced power generation of smaller turbines, and thus the need for more to be installed. Due to the massive offshore wind potential of the US East Coast, the number of turbines is not a major constraint for reaching offshore wind capacity targets. Ultimately, the proposed size standardization is not intended to curb power generation, but rather stimulate a timely installation of offshore wind turbines.

iii. Option 3: Allow unrestricted or market-driven offshore wind industry

The lack of BOEM or DOE incentives towards standard turbine blade sizes has resulted in an environment without a strong mechanism, whether by regulation or standards, to limit the range of turbine sizes. A third option would be to continue allowing completely unrestricted turbine design, which provides wind farm developers flexibility in site selection and tailored turbine design within a site. Through this course of action, the market may eventually adopt proven design sizes.

Advantages

Wind turbines are sized to accommodate an average wind speed. Thus, wind farm site development may benefit from flexibility in design and implementation in comparison to the location (Chamorro et al. 2014). For example, a developer may choose to build many non-standard, smaller turbines in an area with less average wind speed but with better access to an established high-voltage energy transmission network. To make the best use of such a location, a larger standard turbine size may not be efficient compared to more tailored sizes. Adding an additional constraint of turbine size may further limit already constrained wind farm site locations. Unrestricted wind turbine design may also allow flexible power generation within a site and the ability to overcome wake effects between turbines (i.e., air flow from one turbine impeding another) (Feng and Shen 2017). Wind farm developers could therefore custom tailor a range of turbine sizes within a site to generate electricity more efficiently.

Disadvantages

Despite these advantages, unrestricted flexibility of sizing is incompatible with a sustainable manufacturing supply chain or rapid deployment of turbines within the US as supply chains and industrial support cannot readily accommodate unbridled nuance in turbine design (Richards 2023). Development of offshore wind turbines independent of other considerations, such as WTIV requirements, further exacerbates the disadvantages related to the Jones Act, such as the limited vessels that can be used to install larger turbines. Evidently, unrestricted development of the offshore wind industry has demonstrated a degree of near-term planning for WTIV construction that would challenge the ability for the US to quickly install the needed offshore wind capacity.

III. Policy recommendations

Offshore wind energy will play an important role in the US meeting greenhouse gas reduction goals. With the pressure of rising costs and installation challenges, the offshore wind industry in the US would benefit from increased standardization and investment to achieve economies of scale and overcome supply chain, regulatory, and logistical constraints. We urge that DOI and DOE consider the adoption of Option 2 by standardizing the maximum turbine diameter for a 10-year period with the potential to adapt the standards as the industry matures. Government standardization in the permitting or grant stage will incentivize Option 2. Additionally, we encourage the adoption of Option 1 to direct government incentives towards constructing a full fleet of four to six US flagged WTIVs to accelerate the rate of installation and encourage private investment in the offshore wind industry.

Unrestricted market-driven development of the offshore wind industry may be successful in the long run. However, this approach does not promise the achievement of the US goal of 30 GW offshore wind potential and the greenhouse gas emission reduction targets. Ultimately, government incentivization of turbine standardization and investment in appropriately-sized WTIV construction would accelerate and streamline the installation of offshore wind farms to make use of the full renewable energy potential of the available US coastline.

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