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List of Acronyms

CO_2	carbon dioxide
FTE	full-time equivalent
GW	gigawatt
IEA	International Energy Agency
IMPLAN	Impact Analysis for Planning
JEDI	Jobs and Economic Development Impact
MW	megawatt
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
ORBIT	Offshore Renewables Balance-of-System and Installation Tool
ReEDS	Regional Energy Deployment System
SCC	social cost of CO_2
TWh	terawatt-hour
WISDEM	Wind-Plant Integrated System Design & Engineering Model
WTIV	wind turbine installation vessel
yr	year

Executive Summary

On March 29, 2021, the Biden administration announced a national target to deploy 30 gigawatts (GW) of offshore wind power capacity by 2030 (White House 2021a). In parallel with the process of discerning the 30-GW target, the Wind Energy Technologies Office within the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy engaged the National Renewable Energy Laboratory to analyze the impacts of 30 GW of offshore wind on metrics of interest to decision makers. This analysis was conducted against the backdrop of the administration's broader climate objectives of a carbon-free grid by 2035 and considers further decarbonization through electrification of other end-use sectors through 2050; it does not explicitly model the administration's 2050 net-zero economy target. Our analysis was independent of the administration's work to establish the target—it was instead intended to illustrate the potential implications of achieving it.

This report summarizes the methods and findings of our analysis, focusing on the near- (through 2030) and long-term (through 2050) implications of deploying 30 GW offshore wind by 2030. Specifically, we assessed impacts on power sector evolution, offshore wind supply chain and infrastructure, and offshore wind workforce needs in the United States. Table ES-1 contains an enumeration of the studied impacts. Key findings from the work are as follows:

- Meeting the 30-GW-by-2030 target would accelerate offshore wind power deployment, nearly doubling the recent (as of mid-2020) goals of U.S. states and seeding the industry's capacity to support long-term carbon-dioxide emissions reduction goals.

- Our 30-GW-by-2030 target - primary scenario, which extends the analysis to 2050, supports offshore wind deployment past 30 GW in 2030 to nearly 110 GW of offshore wind capacity by 2050. These deployment levels result in offshore wind supplying 2.5% of the national electric sector generation mix in 2030 and 5.8% by 2050.

- Our 30-GW-by-2030 target - primary scenario sees offshore wind power largely developed in the North Atlantic region this decade, with deployment in additional coastal regions in future years. This is one potential pathway of many to reach the target. Floating wind comprises less than 10% of total offshore wind capacity in 2030, but more than 35% by 2050.

- Future offshore wind deployment is observed to be sensitive to a variety of factors. Additional modeled electric sector scenarios that explore technology costs and land availability find 2050 offshore wind deployment ranges from a low of 77 GW (4.2% of U.S. electricity generation) to a high of 255 GW (12.7%), as compared to the 30-GW-by-2030 target - primary scenario 2050 value of 110 GW. On the high end, offshore wind deployment extends into the Atlantic, Gulf of Mexico, Pacific, and Great Lakes. Notably, the range of offshore wind power deployment studied here does not capture the full range of possibilities and future deployments may vary based on factors not considered in the current analysis.

- When evaluated independent of broader decarbonization policy, emissions reductions attributable to the 30-GW-by-2030 deployment target equate to a cumulative reduction of 78 million metric tons through 2030.

- The 30-GW-by-2030 target - primary scenario has significant supply chain implications in the next decade and out to 2050. Between 2023 and 2030, offshore wind buildout requires annual averages of: $12.2 billion in capital expenditures, manufacturing and installation of more than 263 12- to 15-megawatt wind turbines, 886,000 tons of steel, 10,100 tons of permanent magnets, 979 miles of electrical cable; 4–6 Jones-Act-compliant turbine installation vessels—depending on installation strategies—and a minimum of $375–$500 million in port upgrades beyond current plans.

- Achieving 30-GW-by-2030 could support 5–10 new manufacturing plants to produce various offshore wind components: 1–2 manufacturing plants each for wind turbine nacelles, blades, towers, foundations, and subsea cables. The offshore wind sector would consume 0.9% of current annual U.S. steel production, or about 4 years of production from a typical U.S. steel mill.

- From 2041 to 2050, the 30-GW-by-2030 target - primary scenario capital expenditures are $14.9 billion per year, driving a 50% increase in wind turbine demand relative to the 2020s, a doubling or more in annual demand for steel and electrical cabling, and a 90% increase for permanent magnets. As many as nine Jones-Act-compliant turbine installation vessels could be required during this period and minimum port upgrades could be as high as $3.1 billion.

- The 30-GW-by-2030 target - primary scenario results in 77,300 workers employed in offshore wind or in jobs induced by offshore wind activity by 2030, and more than 135,000 by 2050.

- For the period of 2023–2030, construction period installation and supply chain jobs employ approximately 31,300 workers per year on average; by 2030, operation and maintenance (O&M) activities employ 13,400. Construction-period-induced jobs during this time frame in retail, food service, and child-care sectors average 22,800; by 2030, O&M-period-induced jobs total 9,800.

- From 2041 to 2050, construction period installation and supply chain jobs employ 40,800 workers per year on average; by 2050, O&M activities employ 36,700. Construction-period-induced jobs during this time frame average nearly 30,800; by 2050, O&M-period-induced jobs total 26,800.

- Wages for offshore wind jobs conservatively average $66,000 for construction and $55,000 for O&M, with a range of $53,000–$132,000 across all job categories (current year dollars). Wages for induced jobs average $43,000 for the construction period and $39,000 for the O&M period.

Table ES-1. Summary of Estimated Impacts of the 30-GW-by-2030 Target - Primary Scenario (2023–2050) (values rounded)

Impact	2023–2030	2031–2040	2041–2050
Cumulative Deployment (GW at end year [yr])	30	51	110
Deployment Average (GW/yr)	3.7	2.1	5.9
Offshore Wind Energy Generation (terawatt-hour/yr at end year)	117	194	429
Cumulative Capital Expenditures ($billion at end year)	97.4	156	305
Average Capital Expenditures ($billion/yr)	12.2	5.85	14.9
Cumulative Wind Turbine Demand (units)	2,110	3,490	7,440
Average Wind Turbine Demand (units/yr)	263	138	395
Cumulative Steel Demand (thousand tons)	7,090	18,100	38,800
Average Steel Demand (thousand tons/yr)	886	1,100	2,070
Cumulative Permanent Magnets (thousand tons)	80.7	147	337
Average Permanent-Magnet Demand (thousand tons/yr)	10.1	6.65	19
Cumulative Electric Cabling (miles)	9,240	21,000	46,200
Average Electric Cabling (miles/yr)	979	1,180	2,510
Wind Turbine Installation Vessels (minimum working vessels required each year)	4–6	4–6	5–9
Cumulative Port Infrastructure Upgrades Beyond Current Existing or Planned Capabilities ($million)	375–500	375–500	2,330–3,100
[Construction Period] Installation, Manufacturing, and Supply Chain Jobs (thousand full-time equivalents (FTEs)/yr, period average)	31.3	16	40.8
[Construction Period] Induced Jobs (thousand FTEs/yr, period average)	22.8	12.1	30.8
[Operating Period] O&M Technicians, Management, and Supply Chain Jobs (thousand FTEs, at end year)	13.4	19.4	36.7
[Operating Period] Induced Jobs (thousand FTEs, at end year)	9.8	14.2	26.8

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1 Introduction

On March 29, 2021, the Biden administration announced a target to reach 30 gigawatts (GW) of installed offshore wind power capacity by 2030 (White House 2021a). A 100% decarbonization of the electric power sector by 2035 is also targeted by the administration (White House 2021b). These goals could have deep impacts on the U.S. power sector, supply chain, and workforce needs in the period up to and after 2030 and 2035, respectively. In comparison, state-by-state goals for offshore wind as of mid-2020 were estimated to yield 17.4 GW of offshore wind power capacity by 2030 and 25 GW by 2035 (Figure 1). Thus, the new target incentivizes federal and state government agencies as well as regulatory bodies to work with project developers to accelerate and add to prior commitments. Additionally, reaching the 30-GW target by 2030 is expected to result in deployment across several regions, so states and regulators that had no prior commitments to offshore wind power may also experience new investment.

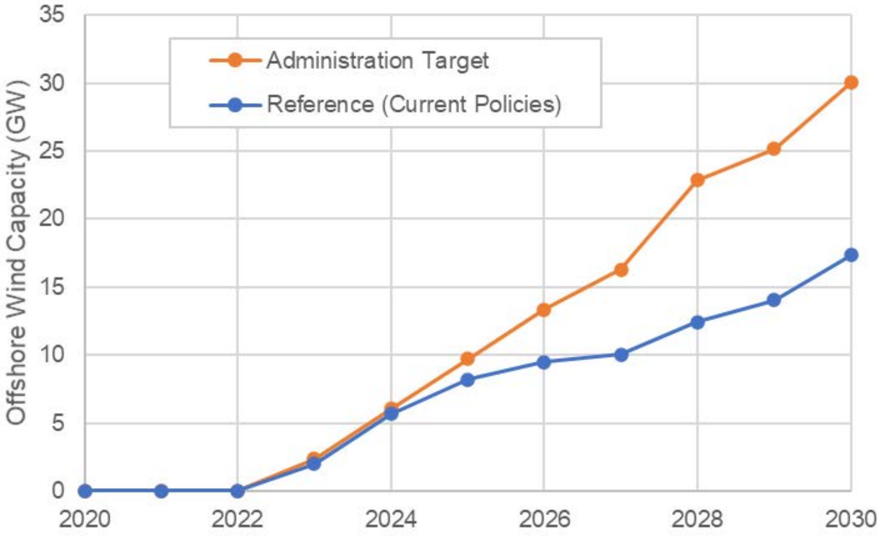

Figure 1. U.S. offshore wind capacity target of 30 GW by 2030 relative to prior state mandates. Current policies reflect state mandates as of June 2020.

In parallel with the process of discerning the 30-GW target, the Wind Energy Technologies Office within the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy engaged the National Renewable Energy Laboratory (NREL) to analyze the impacts of 30 GW of offshore wind on metrics of interest to decision makers. This analysis was conducted against the backdrop of the administration's broader climate objectives of a carbon-free grid by 2035 and considers further decarbonization through electrification of other end-use sectors through 2050; it does not explicitly model the administration's 2050 net-zero economy target. Our analysis was independent of the administration's work to establish the target—it was instead intended to illustrate the potential implications of achieving it.

This report summarizes our analysis, focusing on the near- (through 2030) and long-term (through 2050) implications of deploying 30 GW of offshore wind by 2030. Specifically, we assessed impacts on power sector evolution, offshore wind supply chain and infrastructure, and offshore wind workforce needs in the United States. The methods, limitations, and results of each aspect of the analysis are presented in their respective sections.

2 Power Sector Scenarios

The potential impacts of the 30-GW-by-2030 target are assessed within the context of future scenarios of the U.S. electricity sector through 2050. We develop these scenarios using an electricity sector capacity expansion model for the contiguous United States. The impacts of the offshore wind target include regional near-term and long-term (2050) deployment of offshore wind, expenditures associated with the offshore wind development, and carbon-dioxide (CO2) emissions. These impacts include those from the offshore wind target as well as a broader carbon policy intended to approach the administration's carbon goals and modeled as explained in the following section. Given the uncertainties over the long-term study period, we model a set of sensitivity scenarios.

2.1 Analysis Approach

2.1.1 Power Sector Modeling Methodology

We used the Regional Energy Deployment System (ReEDS) model to simulate the bulk power system scenarios for this study. ReEDS is a publicly available, cost-optimization model of expansion and operation of the electricity system in the continental United States (CONUS) (Brown et al. 2020). In this work, the model finds the optimal portfolio mix for every 2-year period from 2020 to 2050, wherein the optimization is based on the minimum total—capital and operating—expenditures for the system to meet the electrical energy demand, grid-reliability requirements (operating and planning reserves), and policy requirements for 134 model balancing areas and 17 seasonal and diurnal time periods. An array of technology options, including land-based and offshore wind, solar photovoltaics, concentrating solar power, natural gas, coal, nuclear, hydrothermal, biopower, geothermal, batteries, and pumped-storage hydropower, as well as transmission expansion between the model balancing authorities, are considered to meet the system requirements at minimum cost in each model year solve.

ReEDS is unique in the detail it devotes to variable renewable energy technologies, including wind and solar photovoltaics, as well as their interactions with electrical storage technologies. Specifically, it includes an hourly dispatch module to estimate curtailment from the different variable-renewable-energy technology options and the reduction of curtailment from electrical storage. The system also uses 7 years of hourly data to estimate the capacity credit to be awarded the different variable-renewable-energy and storage technology options. The modeled operating reserve requirements include regulation, spinning contingency, and flexibility, and the requirement levels depend on the level of variable-renewable-energy deployment.

Land-based and offshore wind technologies are given a particularly high level of detail in ReEDS. Wind options are considered at 356 resource regions throughout CONUS, 24 different wind classes (10 for land-based, seven for offshore fixed bottom, and seven for offshore floating platform) based on mean wind speeds, and up to five different interconnection cost bins for each combination of region and class. The wind resource characterization is derived from the Renewable Energy Potential Model (Maclaurin et al. 2020), an open-source model of renewable resource potential, and associated hourly generation and interconnection costs. Lopez et al. (2021) and Mai et al. (2021) describe the linkages between the Renewable Energy Potential and ReEDS models as well as the "reference" and "limited access" land-based wind supply curves used for this analysis.

Despite ReEDS' unique capabilities, important limitations exist and are particularly relevant to this offshore-wind-focused analysis. First, ReEDS co-optimizes transmission and generation, but does not have a robust representation of all transmission options. Specifically, high-voltage DC transmission and backbone systems for offshore wind are not fully considered in the model. Second, ReEDS applies a systemwide optimization approach and does not capture all local decision-making considerations, including for offshore wind interconnection, siting, and transmission expansion. Third, ReEDS relies on exogenous assumptions for technology cost improvements, fuel prices, and electricity demand. In other words, technology learning associated with deployment—such as what might occur from a deployment target—is not captured endogenously. Fourth, the sequential version of ReEDS used here does not include foresight of future system conditions, CO2 emissions constraints, or offshore wind targets. Finally, the analysis focuses on scenarios that reach full-grid decarbonization by 2035 but does not include scenarios with full energy system decarbonization, thereby it does not reflect a ceiling for offshore wind energy development in the long term. Additionally, only limited representation of cross-sectoral linkages are modeled in ReEDS.

2.1.2 Scenarios

We developed four scenarios to examine the impacts of the 30-GW-by-2030 target (Table 1). The assumptions for the 30-GW-by-2030 target - primary scenario are summarized in the first row and described in the table. Input assumptions not listed are taken from the 2020 Standard Scenarios Mid-Case (Cole et al. 2020). The ReEDS model version is largely based on the one used for the 2020 Standard Scenarios with additional improvements as discussed by Mai et al. (2021).

Table 1. Input Assumptions in the Scenarios

Scenario Name	Electricity Policy	Renewable Energy and Storage Costs	Land-Based Wind Resource	Electricity Demand
30-GW-by-2030 Target - Primary	***30-GW-by-2030 offshore wind; zero-CO_2 electric power system by 2035***	***Annual Technology Baseline (ATB) 2020 Moderate***	***Reference access supply curve***	***High electrification enhanced flexibility***
30-GW-by-2030 Target - Low Renewable Energy Costs	Same as primary	ATB 2020 advanced	Same as primary	Same as primary
30-GW-by-2030 Target - Limited Land-Based Wind Supply	Same as primary	Same as primary	Limited access supply curve (Lopez et al. 2021)	Same as primary
Business As Usual (No Offshore Target)	State and federal policies as of June 2020 (17 GW of offshore wind by 2030)	Same as primary	Same as primary	Annual Energy Outlook 2020 reference case (Energy Information Administration 2020)

The 30-GW-by-2030 target - primary scenario has state-level mandates for fixed-bottom or floating platform offshore wind in each ReEDS solve year, amounting to 30 GW of offshore wind power deployment by 2030. Importantly, this scenario also assumes that the nation's electric power system is CO2-emissions-free by 2035, and that the economy decarbonizes further by 2050, largely by electrifying transportation, heating, and enhancing demand-side flexibility. The electrification assumptions, including enhanced demand-side flexibility, are from the "Electrification Futures Study: Scenarios of Power System Evolution and Infrastructure Development for the United States" (Mai et al. 2018; Murphy et al. 2021). Annual Technology Baseline (ATB) 2020 moderate costs are assumed for renewable and storage technologies (NREL 2020), and land-based wind resource is based on the reference access scenario from the Renewable Energy Potential Model (Lopez et al. 2021).

The low-renewable-energy-cost sensitivity changes only the renewable energy and storage costs from the ATB moderate to the ATB 2020 advanced technology assumptions (NREL 2020), and the limited-land-based-wind-supply sensitivity changes only the land-based wind resource from reference access to limited access, as described by Lopez et al. (2021).

The business-as-usual scenario, which serves as a baseline for comparison, assumes existing electricity sector policies remain in effect (as of mid-2020), future demand growth with limited electrification as projected in the Annual Energy Outlook 2020 reference case (Energy Information Administration 2020), and no demand-side flexibility. This scenario also does not include the 30-GW-by-2030 offshore wind target but does include recent (as of mid-2020) state offshore wind power policies, which amount to 17.4 GW of offshore wind by 2030 and about 25 GW by 2035. Although inclusive of only a few future possibilities, these scenario sensitivities inform the degree to which future offshore wind power deployment could vary across time and regions.

2.2 Power Sector Scenario Results

2.2.1 30-GW-by-2030 Target - Primary Scenario

Figure 2 shows that in the 30-GW-by-2030 target - primary scenario, 30 GW of offshore wind capacity is prescribed by 2030, after which the modeled carbon policy drives long-term growth in offshore wind to 110 GW by 2050. Annual electricity generation from offshore wind increases from 117 terawatt-hours (TWh) (2.5% of generation in CONUS) in 2030 to 429 TWh (5.8% of generation in CONUS) in 2050. Near-term offshore wind power development is dominated by fixed-bottom systems; however, starting in the mid-2030s, floating platform offshore wind comprises a substantial share of new deployment. As a sequential model that optimizes the portfolio mix in 2-year increments without foresight, ReEDS estimates significant interannual variability in capacity installations—for offshore wind and many other technologies—which are not predictive or reflective of future deployment trends. Given this, we emphasize the multiyear average annual rates of deployment in our analysis. Table 2 shows that the average annual growth of offshore wind capacity increases to 3.7 GW/year (yr) during the 2020s (2023–2030), declines temporarily to 2.1 GW/yr during the 2030s (2031–2040), and increases to 5.9 GW/yr during the 2040s (2041–2050).

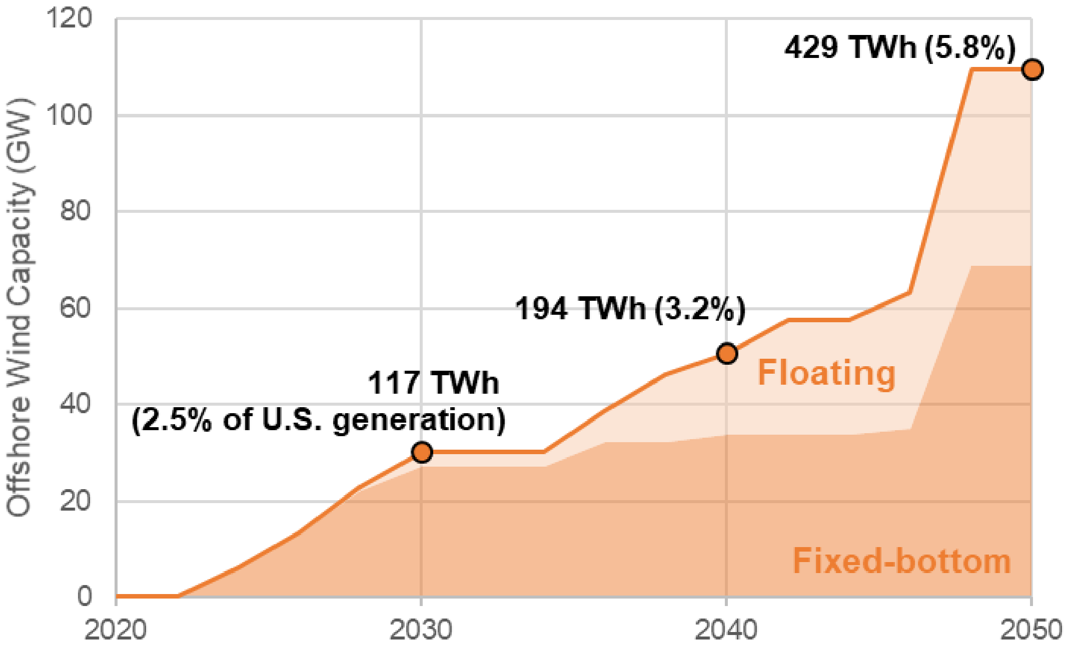

Figure 2. Offshore wind deployment under the 30-GW-by-2030 target – primary scenario

Table 2. Average Annual Deployment Rates in the 30-GW-by-2030 Target – Primary Scenario

Years	Deployment Rate
2023–2030	3.7 GW/yr
2031–2040	2.1 GW/yr
2041–2050	5.9 GW/yr

Figure 3 shows that for this scenario offshore wind is initially developed in the North Atlantic region, which remains the center of offshore wind power development in most years. However, for this scenario greater regional diversity in development occurs starting during the late 2020s (South Atlantic) and mid-2030s (Pacific). More limited offshore wind power development is observed in the Great Lakes (20 megawatts [MW]). Notably, actual regional development may depend on additional factors, such as constraints to land-based wind siting and different advancement projections in clean energy technologies. Future changes in state or federal policy may also impact regional distributions. A wider range of offshore wind power deployment—both in magnitude and by region—are found across scenarios (Section 2.2.2).

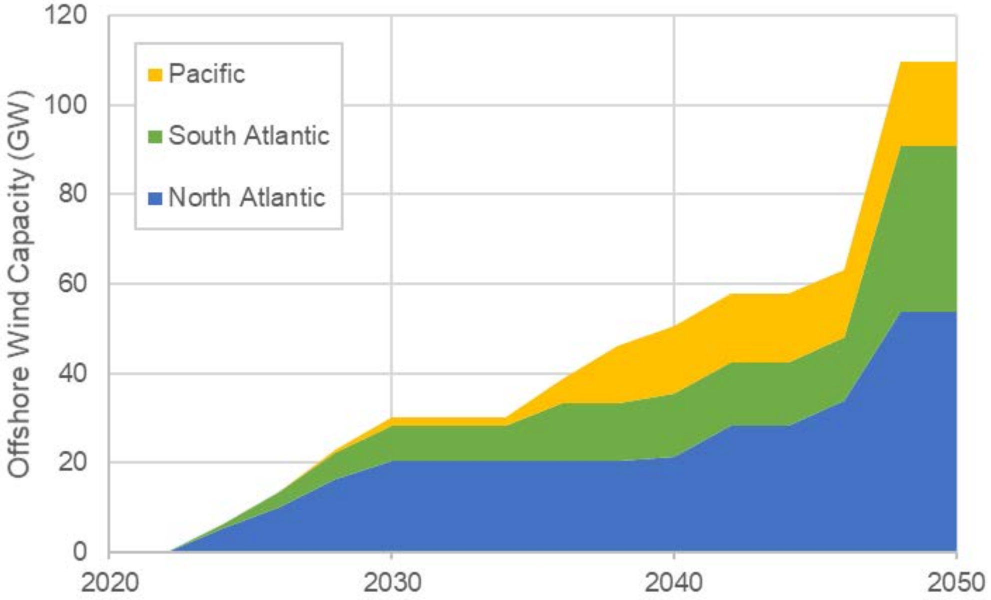

Figure 3. Regional offshore wind power deployment under the 30-GW-by-2030 target – primary scenario. The North Atlantic region includes all Atlantic states north of Virginia. The South Atlantic region includes Virginia. The Great Lakes region observes 20 MW of offshore wind in this scenario but is not visible in the figure.

2.2.2 Low Renewable Energy Cost and Limited Land-Based Wind Supply Sensitivities

Figure 4 shows results from the 30-GW-by-2030 target – low-renewable-energy-costs and the 30-GW-by-2030 target – limited-land-based-wind-supply scenario, which explore how technology cost assumptions and land-based wind siting restrictions can affect the long-term capacity outlook for offshore wind. Even though the 30-GW-by-2030 target – low-renewable-energy-costs sensitivity has lower offshore wind costs than the 30-GW-by-2030 target - primary scenario, it has lower costs for competing clean energy technologies including land-based wind, solar, and storage, which can reduce the overall amount of offshore wind power deployment in the long term. In this case, there is a reduction in 2050 offshore wind generation market share from 5.8% in the 30-GW-by-2030 target - primary scenario to 4.2% in the 30-GW-by-2030 target – low-renewable-energy-cost sensitivity. However, offshore wind can also diversify the clean electricity portfolio and help hedge against potential challenges associated with siting and land-use conflicts for other renewable energy technologies. Results from the 30-GW-by-2030 target – limited-land-based-wind-supply sensitivity demonstrates this with nearly 13% of generation market share from offshore wind by 2050 from over 250 GW in installed capacity. In this scenario, we also observe significant development of offshore wind capacity in all regions, including the Gulf, Great Lakes, and Pacific regions. Again, actual future offshore wind power regional distributions may depend on factors not modeled in these scenarios.

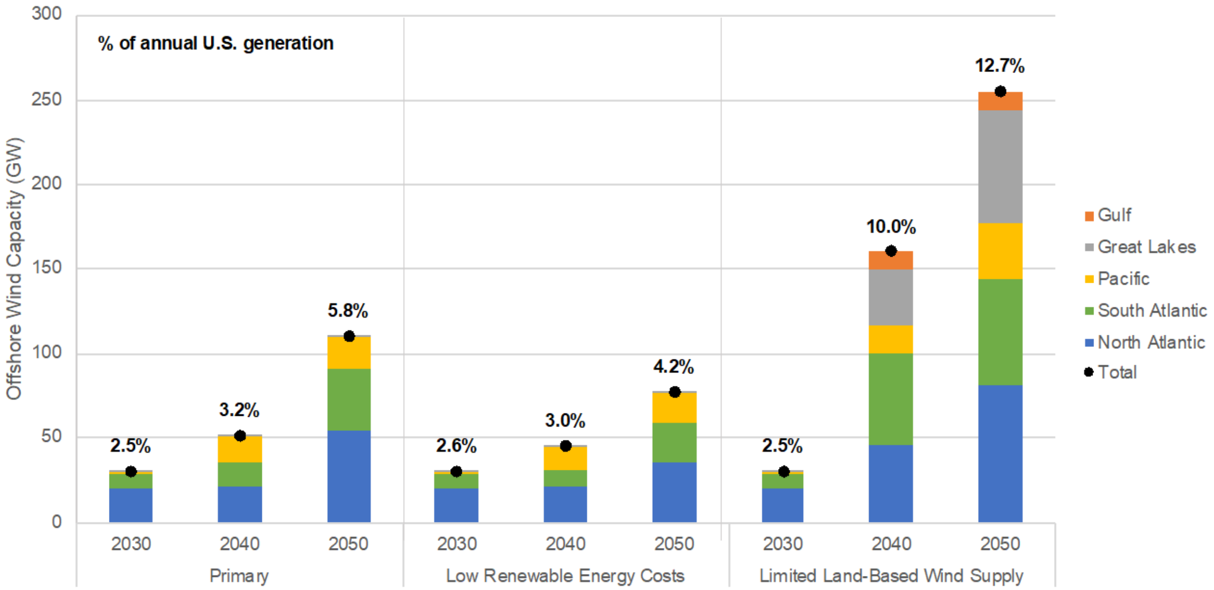

Figure 4. Total and regional offshore wind power deployment under the three 30-GW-by-2030 target scenarios. The North Atlantic region includes all Atlantic states north of Virginia. The South Atlantic region includes Virginia.

2.2.3 Emissions Impacts

The first three scenarios in Table 1 (30-GW-by-2030 target - primary, 30-GW-by-2030 target – low-renewable-energy costs, and 30-GW-by-2030 target – limited land-based wind supply) all include an increasingly stringent CO2 emissions cap (that eliminates those emissions from the electricity system by 2035), significant electrification of other energy sectors, and the 30-GW-by-2030 offshore wind target. In contrast, the business-as-usual scenario does not include any of these assumed policies. Figure 5 shows the combined effect of these policy assumptions on energy-related CO2 emissions (in million metric tons [MMT]), wherein the leftmost chart represents the business-as-usual scenario, the middle chart represents the three target scenarios, and the rightmost shows the avoided emissions of the target scenarios relative to business as usual. The target scenarios result in 62% energy-related emissions reductions (relative to 2005) by 2050 through zero-carbon electricity and electrification. Compared to the business-as-usual scenario, 2.2 billion metric tonnes of CO_2 are avoided in 2050, wherein avoided emissions are roughly evenly split between the power sector and the demand sectors.

Although the scenarios represent complete grid decarbonization by the mid-2030s, they do not reflect efforts to fully decarbonize the energy sector. Decarbonization levels beyond what is modeled could result in additional electrification or electricity consumption for low-carbon fuel production, which could be met, in part, by incremental offshore wind deployment. In addition, the avoided emissions reported are primarily a result of the assumed electrification and emissions cap and cannot be fully attributed to the offshore wind target. Text Box 1 presents an estimate of the isolated emissions impact of 30 GW of offshore wind independent of all other carbon considerations.

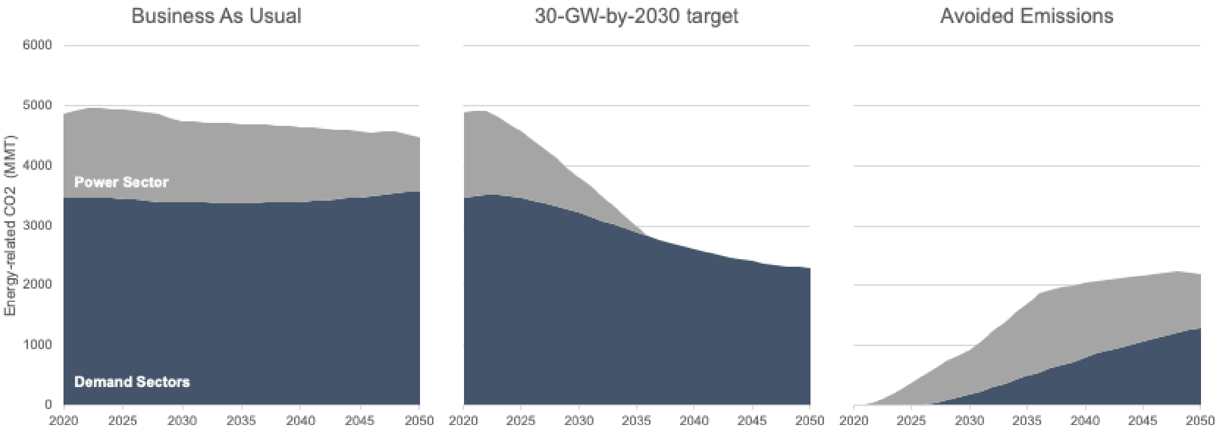

Figure 5. Energy-related CO_2 emissions in the scenarios

Text Box 1: Emissions Impacts of the Offshore Wind Target

To isolate the emissions impact of the 30-GW-by-2030 offshore wind target in the absence of a broader carbon policy, we compare the emissions from the business-as-usual scenario with another scenario that adds the 30-GW-by-2030 target, without the broader carbon policy or electrification assumptions. Figure 6 shows that accelerating offshore wind energy with the 30-GW-by-2030 target would reduce 78 MMT in cumulative CO_2 emissions through 2030 and 288 MMT through 2040, as compared to existing state policies.

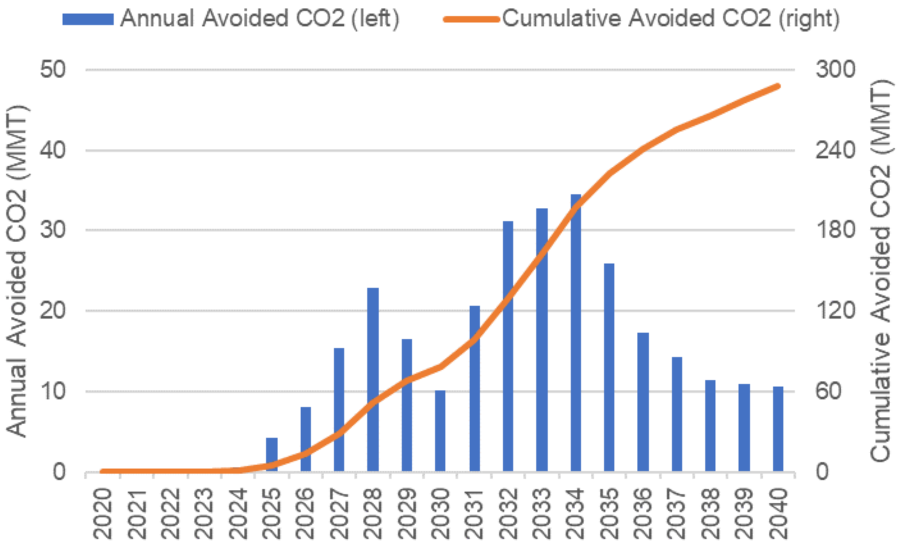

Figure 6. Avoided CO_2 from the 30-GW-by-2030 offshore wind target as compared to the without-offshore-wind target case under business-as-usual conditions

3 Supply Chain Projections

The supply chain analysis detailed here is intended to translate the offshore wind regional deployment schedule from the ReEDS model into its impact on the U.S. manufacturing sector and critical support infrastructure. The manufacturing supply chain impacts focus on the demand for select raw materials (e.g., total tons of steel) and key quantities (e.g., number of wind turbine blades). The infrastructure impact focuses on the ports and vessels necessary to deploy large capacities of offshore wind power. Although this assessment is not comprehensive of all potential supply chain and infrastructure impacts, it includes the primary domains that are readily quantifiable and a sizable majority of the potential investment.

3.1 Analysis Approach

We separated the supply chain analysis into two components, each with their own modeling approach, assumptions, and limitations:

1. Supply chain demand for capital, wind turbine and plant components, and raw materials
2. Infrastructure expansion required to support the deployment targets.

Both elements of the supply chain analysis used the ReEDS model output of offshore deployment over time through 2050 as input.

3.1.1 Capital, Components, and Raw Materials

We applied deployment and capital expenditure results from ReEDS to estimate supply chain impacts using a variety of tools, including NREL's Wind-plant Integrated System Design and Engineering Model (WISDEM®) for wind turbine costs and materials (Ning et al. 2014), and Offshore Renewables Balance-of-System Installation Tool (ORBIT) for balance-of-system costs (Nunemaker et al. 2020). ReEDS provided a deployment figure and capital expenditures broken down by region at each time step in the simulation. ReEDS also specified whether a given regional deployment used fixed-bottom or floating platform supports. WISDEM processed each regional deployment estimate to generate a hypothetical power plant design, with the cost and material demands for each major component tallied to estimate regional supply chain demand. This process created a supply chain demand schedule for the scenario.

More specifically, we used WISDEM to process the ReEDS regional deployment values to build hypothetical plant capacity and number of wind turbines. We took the plant capacity as the ReEDS value directly, if less than 1 GW, otherwise we divided it into multiple plants/projects such that nameplate capacity was less than 1 GW. We assumed the turbine rating to be 12 GW until 2025, reflecting the market availability of the GE Haliade-X, after which we used a 15-MW rating. We derived wind turbine mass and cost breakdowns from an NREL approximation of the GE Haliade-X at 12 MW, and the International Energy Agency (IEA) Wind Task 37 15-MW reference wind turbine otherwise (Gaertner et al. 2020).

Once we set the project and turbine ratings, we optimized the wind turbine support structure for the archetype meteorological ocean conditions (e.g., water depth, wind speed distribution, wave height) for each region with WISDEM. ReEDS specified a project as using either a fixed-bottom or floating support structure, so both variants were developed for each region. For the fixed-bottom projects, we optimized monopiles at each region-specific depth. For the floating project, we assumed use of the Volturn-S semisubmersible design from the floating variant of the IEA Wind Task 37 15-MW reference wind turbine (Allen et al. 2020) in all regions. However, we optimized the mooring system for each region-specific depth, assuming catenary chains.

With a more detailed support structure specified in WISDEM, we then used ORBIT to compute balance-of-system costs and the electrical system design for the desired plant size at an average distance from shore for each region. Within ORBIT, fixed-bottom wind turbines with monopiles were installed with traditional wind turbine installation vessels (WTIVs), whereas floating wind turbines with semisubmersibles were assembled at port and towed to the location. Novel turbine installation strategies such as telescoping towers that may remove the need for WTIVs were not considered. We assumed the array cables to be 66 kilovolts and export cables to be 220 kilovolts, with the wind turbines connected via radial strings and the export cable connected to shore via the shortest straight-line path distance. The summation for “cabling” demand includes both array and export cables. Novel or coordinated interconnection and transmission strategies were not considered.

To breakdown the conceptual plant and turbine design into supply chain and capital expenditure streams, we tallied the raw material demand and cost for all major components for all wind turbines by year. This raw material demand was an output of WISDEM, with cabling length reported by ORBIT. We apportioned the aggregate capital expenditures from ReEDS to all major components based on WISDEM and ORBIT percentage cost estimates. This was then used in Jobs and Economic Development Impact (JEDI) models to estimate new jobs in the manufacturing and logistics sectors.

Note that there are some biases introduced by these assumptions. If wind turbines grow beyond 15 MW, then fewer turbines and supplies will be needed to meet a desired capacity than our analysis shows. If project sizes tend to be smaller than 1-GW increments, more electrical cabling will likely be needed. Additionally, our analysis likely underestimates the required amount of cable as real-world projects will require longer export routes to avoid sensitive marine areas and to reach reasonable interconnection points (which may not be located at the closest point to shore). This effect may be offset be real projects using more optimized cable designs that reduce line lengths. For floating deployments, our assumption of catenary chain mooring systems is an oversimplification that biases the amount of steel demand upward since semitaut and/or synthetic lines will likely play a role. However, the synthetic lines will have their own U.S. supply chain that we do not track. Finally, the assumption of one active WTIV per project provides a baseline demand estimate; however, the availability of additional vessels would likely be desirable for project developers to alleviate bottlenecks and install different project phases in parallel.

3.1.2 Wind Turbine Installation Vessels

We also estimated the number of WTIVs required to support the ReEDS deployment pipeline. The method applied established an average installation time per wind turbine based on vessel tracking data from offshore wind power project installations in Europe. Three installation methodologies were considered:

1. A Jones-Act-compliant WTIV[1] transports wind turbines and foundations from the port and installs them at site (5.3 days/turbine).
2. A Jones-Act-compliant feeder barge transports wind turbines and foundations from the port and a WTIV (which does not have to be compliant with the Jones Act) installs the components at site (3.4 days/turbine).
3. A Jones-Act-compliant feeder barge transports wind turbines from the port and a WTIV (which does not have to be compliant with the Jones Act) installs the components at site on foundations that have been preinstalled using a method that does not require a WTIV (1.6 days/turbine).

Assuming a 9-month installation window per year (or 75%) because of weather and marine mammal restrictions, the number of WTIVs required to install the number of fixed-bottom wind turbines in each 2-year ReEDS deployment bin was calculated as:

$$WTIVs = \frac{(Number\ of\ turbines\ installed\ in\ 2\ years) \times \left(\frac{days}{turbine}\right)}{0.75\ \times 2\ years\ \times 365\ \frac{days}{year}}$$

This approach assumes that no WTIVs are required to install floating wind turbines and does not consider any additional vessel demand for related construction, operation, and servicing activities, as these ancillary vessels are not expected to create the same bottleneck as the limited global WTIV fleet.

The cost of building a U.S.-flagged WTIV is uncertain, and we derived a range of values from press releases, published literature, and communication with shipbuilders (Dominion Energy 2021; Cheater 2017). As the exact costs of building one of these vessels is uncertain, we provide a low and a high cost to build a WTIV ($100 and $500 million, respectively) and demonstrate the range of investment required to build the maximum vessel demand. In addition, we estimate that 11,000 tons of steel are required to build a WTIV and provide the associated steel demand (Dominion Energy 2021; private communication).

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[1] The Jones Act requires vessels transporting components between U.S. ports (which includes offshore wind turbine foundations) to be built, owned, and operated by U.S. citizens or permanent residents.

3.1.3 Ports

To estimate demand for new ports to achieve the 30-GW-by-2030 offshore wind target, we assume that the current pipeline (17.4 GW by 2030) can be supported by existing or planned port infrastructure, even if these ports are suboptimal for offshore wind deployment. Therefore, additional port infrastructure needs to be developed to support the remaining 12.6 GW that would be installed by 2030 to meet the target. This demand for port infrastructure is parameterized by the number of berths required to support the loadout of wind turbines and foundations, which assumes that the associated facilities (e.g., manufacturing space, laydown area, bearing capacity, wet storage, navigation channels) are developed commensurately with the number of berths.

This approach assumes that each installed wind turbine requires a dedicated berth at a port for its installation window, and that the maximum installation time per turbine and foundation (5.3 days) from Section 3.1.2 is required for both fixed-bottom and floating wind turbines. The number of berths required to install the incremental number of turbines above the current 17.4-GW pipeline to reach the 30-GW target was calculated as:

$$Berths = \frac{((Number\ of\ turbines\ )_{30GW} - (Number\ of\ turbines\ )_{17.4GW}) \times \left(\frac{days}{turbine}\right)}{0.75\ \times 2\ years\ \times 365\ \frac{days}{year}}$$

This approach uses the same installation window assumptions as the WTIV calculation. While it is conservative, as it does not consider parallelizing operations at quayside, it also does not capture the additional port demand for electrical system installation; scour protection installation; surveys; operation and maintenance; and a range of other project activities. Notably, because wind turbine and foundation loadout will place the heaviest demand on port infrastructure, these parameters are used as an indicator of the overall port infrastructure requirements.

The cost to upgrade port infrastructure is extrapolated from the reported costs for the New Jersey Wind Port, which estimates \$300–\$400 million to develop four state-of-the-art offshore wind berths with supporting manufacturing, storage, and assembly facilities. Based on this metric, we assume a value of \$75–\$100 million per new berth constructed, which does not include estimated costs for port projects already under development.

Ultimately, port design is a multifaceted challenge that will require significant customization for both East and West Coast offshore wind ports. The analysis and results detailed here are intended to provide an initial assessment of required needs and investment magnitude.

3.2 Supply Chain Impacts Results

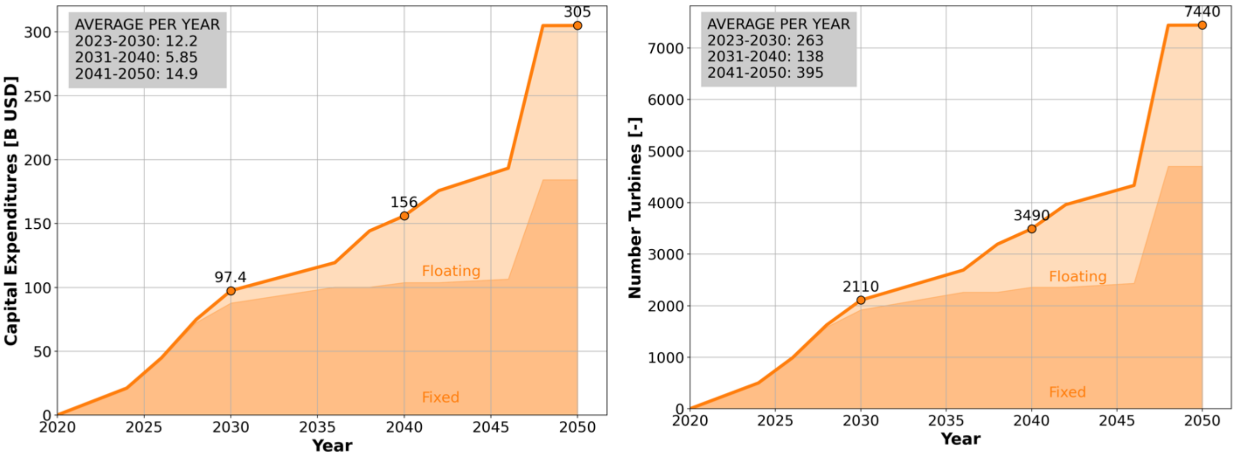
3.2.1 Capital, Components, and Raw Materials

The supply chain demand for the 30-GW-by-2030 target - primary scenario in terms of capital, components, and raw materials is summarized in Table 3. Given that observed ReEDS interannual variability noted earlier is not predictive or reflective of future deployment trends, the table lists the average annual demand by decade and marks the cumulative demand in 2030, the year of the 30-GW deployment target, and in 2050, as offshore wind buildouts progress to meet the carbon emissions reduction goals.

Table 3. Supply Chain Components and Commodity Demand in the 30-GW-by-2030 Target - Primary Scenario (values rounded)

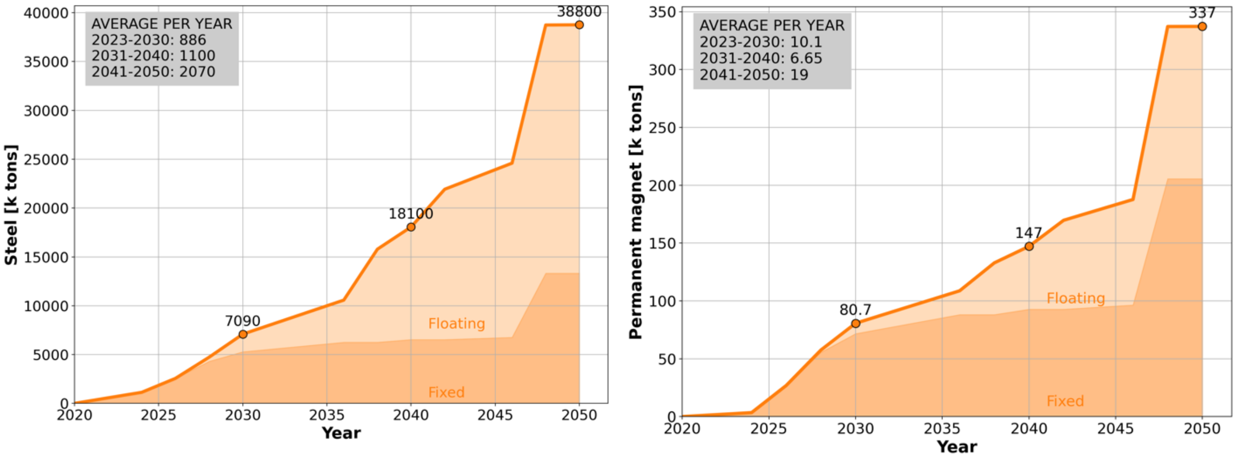
	2023–2030 Average [/yr]	2030 Total	2031–2040 Average [/yr]	2041–2050 Average [/yr]	2050 Total
Total Capital Expenditures [$billion]	12.2	97	5.9	14.9	305
Turbine Capital Expenditures [$billion]	5.8	47	2.3	6.5	134
Foundation Capital Expenditures [$billion]	1.7	14	2.1	4.0	75
Wind Turbines [-]	263	2,110	138	395	7,440
Blades [-]	790	6,330	415	1,190	22,300
Towers [-]	263	2,110	138	395	7,440
Nacelles [-]	263	2,110	138	395	7,440
Foundations [-]	263	2,110	138	395	7,440
Steel [thousand (k) tons]	886	7,090	1,100	2,070	38,800
Permanent Magnet [thousand (k) tons]	10.1	80.7	6.6	19.0	337
Cabling [miles]	979	9,240	1,180	2,510	46,200

For some of the quantities listed in Table 3, a more detailed timeline progression of the cumulative supply chain demand is shown in Figure 7, with further breakdowns in fixed-bottom versus floating deployments and average annual demand. Because they are coupled to the deployment forecasts discussed in Section 2, many of the supply chain quantities follow a similar trend to that shown in Figure 2. The bulk of the deployments prior to 2030 are in fixed-bottom wind turbines along the Atlantic Coast. The small quantity of floating wind turbines, however, requires higher amounts of steel (for the mooring lines) and electric cabling (further distance from shore) per turbine. With the 30-GW target, there are more than 2,100 offshore wind turbines deployed, requiring a total capital expenditure of approximately $97 billion. After 2030, the deployment is dominated by floating wind turbines on the West Coast and further offshore (in deeper water) on the East Coast, thereby making the steel and electric cabling demand grow more quickly than other commodities. Not included in the results shown in Table 3 or Figure 7 are the capital expenditures required to build additional manufacturing facilities to support the offshore wind power deployments.



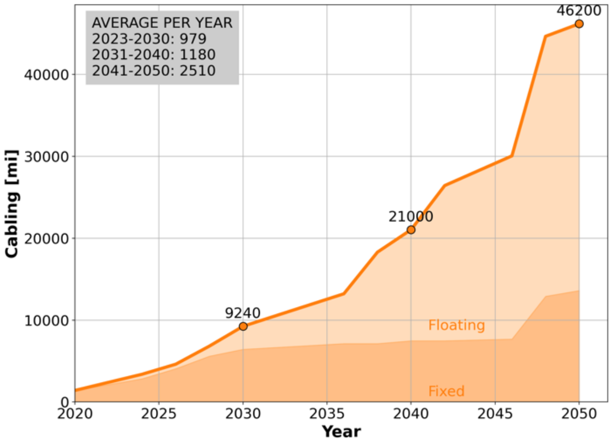
(a) Capital expenditures in $U.S. billions

(b) Number of wind turbines



(c) Amount of steel (thousands of tons)

(d) Amount of permanent magnets (thousands of tons)



(e) Length of electrical cabling (miles [mi])

Figure 7. Projected capital expenditures and number of offshore wind turbines through 2050

To provide additional context to the supply chain demand volumes, we compared the demanded quantity of steel and turbine components to a typical factory output. The average annual output per factory, compiled from a variety of press release and related industry sources, in Table 4 can help give a rough estimate for the investment needed in manufacturing facilities when combined with Table 3 and Figure 7.

Table 4. Production Facilities Required To Meet the 2020-2030 Annual Supply Chain Demand
(Sources include a variety of publicly available press releases and industry characterizations compiled by the authors)

Production Facility	Annual Output	Number Needed To Meet 2030 Target
Steel Mill	1,500,000 tons/yr	1
Monopile Factory	165 units/yr	2
Tower Factory	155 units/yr	2
Nacelle Factory	250 nacelles/yr	2
Blade Factory	600 blades/yr	2
Export Cable Fabrication	121 miles/yr	8

As an initial means of translating these additional investments, which could accrue in coastal U.S. communities, into capital expenditures, we conducted a brief literature review to estimate their potential dollar value. From prior examples in Europe, each wind turbine blade, nacelle, or foundation manufacturing facility may cost \$200–\$300 million (Tisheva 2015; Dillinger 2019) and a cable manufacturing facility may cost around \$200 million (Katteland 2020). In principle, these costs could be multiplied by the number of potential new facilities required to support the offshore deployments.[2]

3.2.2 Supply Chain Infrastructure: Wind Turbine Installation Vessels

Figure 8 shows the demand in WTIVs per 2-year ReEDS deployment window and the corresponding number of wind turbines installed. The three scenarios include the Jones-Act-compliant WTIV (solo WTIV), the WTIV supported by Jones-Act-compliant feeder barges (WTIV + feeders), and a WTIV supported by a feeder barge that installs wind turbines on preinstalled foundations (WTIV for turbines only).

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[2] These facilities could support land-based deployments as well, but this is not tracked in this work.

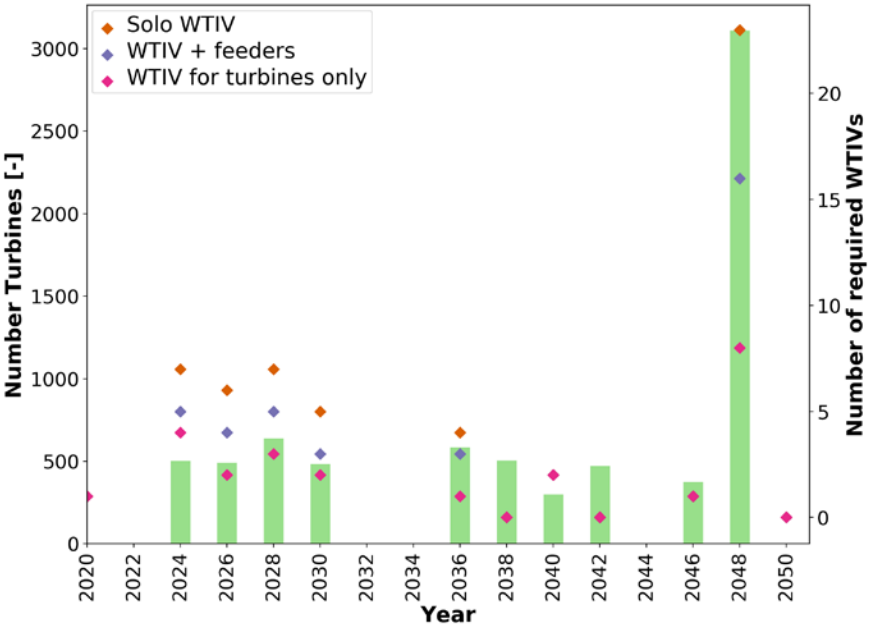

Figure 8. Number of wind turbines (left axis) and wind turbine installation vessels (right axis) required by year

The demand for Jones-Act-compliant WTIVs varies with the deployment pipeline in the next decade, typically requiring 4–6 vessels (depending on installation method) and dropping to zero in 2031–2032. This range reflects the variance in the annual deployment projections and indicates a need to stabilize the pipeline to provide a consistent and predictable stream of revenue to justify the initial capital investment in WTIVs. As discussed in Section 2.1.2, the results from the ReEDS model exhibit significant interannual variability, which is the source of the lulls in 2032, 2034, 2044, and 2050, as well as the spike in deployment in 2048. A more realistic demand based on decadal average deployment would require 2–4 WTIVs per year, although it is worth noting that annual peaks in deployment will likely still exist; as such, we report the maximum WTIV demand in the 2020s and 2030s to consider the highest potential demand. The modeled demand for over 20 WTIVs in 2048 would likely be spread over a longer time period for real deployment, and as such we estimate a maximum demand of 5–9 WTIVs in the 2040s to smooth out this projection.

WTIV demand is reduced for scenarios that take advantage of feeder barges and alternate foundation strategies, as some of the installation work is diverted away from the WTIVs. While these strategies do not require Jones-Act-compliant WTIVs, which could allow international vessels to gain market share for U.S. projects, they would also promote additional domestic development of feeder barges and the alternate foundation supply chain (for example, concrete gravity-based foundations). Additional study is required to understand the most cost-effective and lowest-risk approach for the U.S. market. The capital investment and steel demand for increasing levels of Jones-Act-compliant WTIV fabrication are shown in Figure 9.

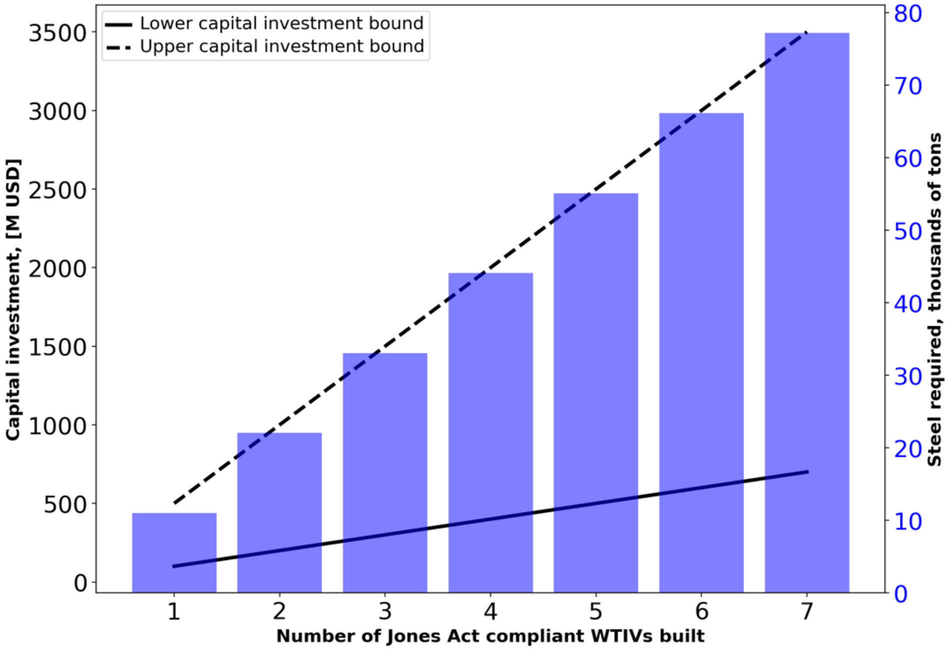

Figure 9. Capital expenditure in $U.S. millions (left) and steel (in thousands of tons) by year

3.2.3 Supply Chain Infrastructure: New Port Development

Figure 10 shows the additional port infrastructure, parameterized by the number of berths, which are required to support the 30-GW buildout beyond the mid-2020 17.4-GW deployment projections. Up to five berths are required to support wind turbine and foundation installation in the 2027–2028 ReEDS deployment window, which can be interpreted as needing approximately another New Jersey Wind Port to be developed on the Eastern Seaboard to support the deployment targets. This demand represents the minimum viable port upgrade, as additional berthage and support infrastructure will be required to support activities beyond turbine and foundation installation. As this analysis does not consider the location of the new port facilities, additional costs may be incurred to develop ports or marine terminals with closer proximity to specific projects. In reality, more port facilities may well be constructed to satisfy regional demand and local content requirements. The demand decreases in the early 2030s as the deployment projections slow, but then accelerates in the mid-2030s. Similar to the WTIV demand, varying offshore wind deployment will provide a challenge to developing and leasing custom offshore wind ports unless more consistent revenue streams can be achieved.

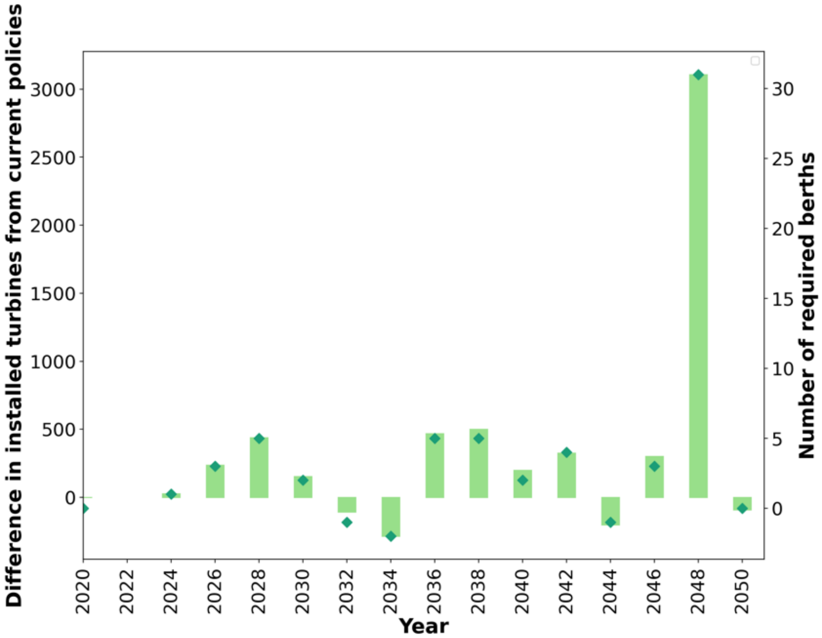

Figure 10. Difference in installed wind turbines from current policies (left) and number of required berths (right) by year) under the 30-by-2030 target

The potential cost to develop the additional berthage is shown in Table 5. This number identifies the highest port demand per decade and applies an investment cost of $75–$100 million per berth. The reported capital expenditure is the cumulative amount that would need to be spent throughout the 2021–2050 timeline. Of course, if demand is more stable than characterized in ReEDS, as is likely, investment during the 2040s may be reduced in line with a lower peak demand.

Table 5. Required Number of Berths and Capital Expenditures in 2023–2030, 2031–2040, and 2040+

	2023–2030	2031–2040	2040+
Required berths for wind turbine/foundation installation	5	5	31
Investment cost	$375–$500 million	$375–$500 million	$2,330–$3,100 million

4 Jobs and Economic Impact

Offshore wind power represents an opportunity to develop a new industry in the United States, with expected job creation to develop, manufacture, construct, and operate these wind power plants while spurring economic development near ports and in the supply chain. In 2019, the wind industry employed approximately 115,000 workers across development, manufacturing, construction, and operations (National Association of State Energy Officials and the Energy Futures Initiative 2020), with most of these jobs associated with land-based wind power. This jobs and economic impact analysis provides an estimate of the jobs and earnings supported by the offshore wind power industry in the short term (e.g., 30 GW by 2030) and long term (e.g., 110 GW by 2050) under the 30-GW-by-2030 target - primary scenario, accounting for activity in the supply chain and the associated offshore wind power plant costs.

4.1 Analysis Approach

We used the NREL JEDI model (NREL 2021) to estimate jobs and economic impacts for the 30-GW-by-2030 target - primary scenario. The JEDI model is an input-output model used to estimate economic impacts associated with investment or expenditures from constructing and operating power plants. Its inputs include capital and operational expenditures, domestic content assumptions, and an aggregation of economic multipliers from IMpact Analysis for Planning (IMPLAN 2021), as well as labor data. NREL used the recently updated offshore-wind-specific JEDI model for this analysis.[3]

4.1.1 Model Inputs and Scope

Expenditures considered in JEDI are limited to project-level capital and operational expenditures. Accordingly, our analysis focused on all construction- and operations-related activities (e.g., manufacturing and assembly) but it did not assess the jobs and economic impact of a priori investments in port infrastructure upgrades, vessel construction, or manufacturing facility construction. While these impacts were outside the scope of this analysis, additional jobs and economic activity would be supported from the development of these assets.

We defined the primary construction and operation and maintenance (O&M) inputs for JEDI as part of the ReEDS deployment scenarios, WISDEM and ORBIT cost modeling, and supply chain projections. The ReEDS capacity expansion model provided the deployment scenarios and total capital expenditures for the 30-GW-by-2030 target - primary scenario. The deployment levels and total capital cost ($/kW) were modeled on an annual basis in JEDI. Cost inputs in the JEDI model are further broken down into several categories including wind turbine component, balance of system, and operational expenditures. The WISDEM and ORBIT models provided a cost breakdown at the component and balance-of-system levels. Aggregated capital expenditures from ReEDS were apportioned to all major components based on the cost breakdown from the WISDEM and ORBIT models. Four cost breakdowns were provided based on technology

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[3] We used a beta version of JEDI for this analysis, which was undergoing testing at the time of this study. The first update after estimates were produced for this study was April 26, 2021. The changes made in this update have been determined to have insignificant impacts on results.

characteristics, including a 12-MW fixed-bottom, 12-MW floating, 15-MW fixed-bottom, and 15-MW floating system.

The JEDI model allows a model user to specify which portions of expenditures are made within an area of analysis. In this assessment, which was intended to capture the full breadth of national employment and labor force needs, the United States was selected as the area of analysis. This approach allowed us to quantify the total expected domestic workforce demand across the supply chain necessary to serve the offshore wind industry, inclusive of potential demand in coastal and interior regions. Accordingly, all local content assumptions were based on United States domestic content estimates. To accomplish the desired objectives of the analysis, we used economic multipliers and personal consumption expenditure patterns for the full United States to derive the results. The national multiplier data included employment, wage and salary income, value added (gross domestic product), and output (economic activity). All multiplier and household expenditure data were derived from IMPLAN, using data year 2019.

As with all economic models, there are caveats and limitations to the use of the JEDI model. Input-output models use fixed, proportional relationships between economy sectors. Factors that could change economic sectors, such as price changes that lead households to change consumption patterns, are not considered. Moreover, actual employment results may vary if the future offshore wind supply chain deviates substantially from industries that currently provide similar services either in the manner in which they serve demand or in the locations where products are produced in service of offshore wind demand. Notwithstanding these fixed relationships derived from historical data, the dollar expenditures themselves change per unit of capacity because of ORBIT, WISDEM, and ReEDS cost characterizations that reflect different project inputs, economies of scale, and technological growth.

Results from JEDI models are gross, not net. They reflect the estimated employment demand and associated economic activity for a given expenditure, independent of the dynamic nature of the broader economy. In this vein, gross impacts from JEDI are more akin to workforce needs from a project and the economic activity associated with these needs. More specifically, JEDI calculates the economic activity that would be supported by increases in demand, created by project expenditures, but does not evaluate potential changes in economic activity from associated reductions in demand in other subsectors, which might occur as a result of a shift in expenditure. In addition, other macroscopic economic changes may take place that JEDI does not consider, including price changes, changes in taxes or subsidies, tariffs on foreign steel, or utility rate changes. All of these changes could affect the net impacts by decreasing or increasing household expenditures on items other than electricity. Supply-side price changes could also influence economic activity by changing consumption patterns (i.e., how much of each good or service is consumed by households and businesses) and these effects are not considered. Further, JEDI does not incorporate far-reaching effects such as those caused by greenhouse gas emissions, displaced investment, or potential side effects of a project such as recreation or tourism. Factors not considered by JEDI that could be incorporated into a net analysis could influence results positively or negatively.

4.1.2 Results Categories and Definitions

For this analysis, we used JEDI to report jobs and associated earnings. Each result has a specific definition that informs how it should be interpreted:

- **Jobs**. JEDI reports all job figures as full-time equivalent (FTE). One FTE is the equivalent of one person working full time for 1 year (2,080 hours). Two people working half time for 1 year, for example, are the same as one FTE. An FTE could alternately be referred to as a person-year or job-year.

- **Earnings**. Earnings are any type of income from work; generally, an employee's wage or salary and supplemental costs paid by employers, such as health insurance and retirement.

Jobs and earning results are further broken out into three categories specific to the construction period, inclusive of manufacturing and installation, and the operations period, inclusive of those activities that make up the postconstruction O&M period of the plant life cycle. For construction, job results are estimated on an average annual basis across time periods of 2023–2030 and 2031–2040, and 2041–2050 to smooth out fluctuations in job requirements based on the modeled plant installations for each ReEDS deployment scenario. This approach is consistent with that taken for the supply chain analysis, in terms of reporting results. For operations, job results are provided on an annual basis in 2030, 2040, and 2050 and reflect the operations activity for all operating offshore wind power plants in that year.

Construction job categories include:

- **Installation activities**: jobs related to vessel and ports activities to support construction of offshore wind power plants, including fixed-bottom or floating substructures, wind turbine erection, array and export cabling, and scour protection

- **Component manufacturing and supply chain and support services**: jobs related to producing wind turbine components (e.g., nacelle, blades, towers, monopiles, electrical cabling) including support from the supply chain to source domestic materials and labor as well as development jobs such as site assessment and project planning

- **Induced**: jobs related to the additional domestic spending from installation and supply chain workers spending earnings along with any other money circulating in the economy from direct and indirect impacts; an example of an induced job is a server in a local restaurant where offshore wind port and staging workers eat lunch.

O&M job categories include:

- **Technicians and management**: jobs related to workers servicing the plant, water transport from port to plant, and engineering and management support

- **Support services and supply chain**: annual jobs related to supply chain activities including manufacturing and inventory of replacement components, production of plant maintenance materials, and other equipment

- **Induced**: jobs related to the additional domestic spending from O&M workers spending earnings along with any money circulating in the economy from direct and indirect impacts during plant operations.

4.1.3 Domestic Content Scenarios

Domestic content is the percentage of total expenditures spent in the United States to construct and operate an offshore wind power plant. These percentages are a primary input in the JEDI model and represent a set of assumptions on how much labor or materials will be spent in key segments of the offshore wind industry, including component manufacturing and supply chain or workers supporting ports and vessels.

We applied a low- and high-domestic content scenario to the ReEDS capacity expansion model scenarios. For offshore wind capacity deployed up to 2025, we assigned a low-domestic-content scenario to expenditures to reflect the fact that—even if supply chain investments are made immediately—such capacity would not be available overnight. For plant capacity installed between 2025 and 2050, we modeled a high-domestic-content scenario to represent a higher utilization of local workforce, vessels, ports, and supply chain. While domestic content is ultimately likely to vary across components, we apply consistent values across most components here because of a high degree of uncertainty in what future component-level domestic content could be, and because the focus of this study is on project-level rather than component-level jobs. The assumed values are provided in Table 6.

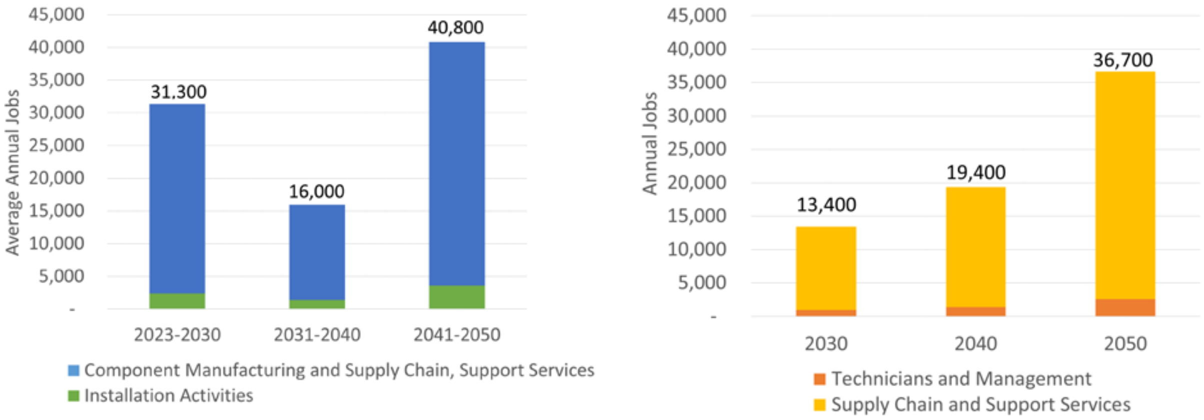
Generally, the low-domestic-content scenario (up to 2025) assumes manufacturing plants produce major components, but limited plant production and supply chains lead to import of most components. At the same time, it assumes that vessel operators hire U.S. workers, but most vessels are not U.S.-flagged, reducing workforce utilization. Port infrastructure is assumed to be capable of supporting most installation activities. For the high-domestic-content scenario (2025–2050) additional manufacturing plants are assumed to be built to meet the majority of offshore wind demand. Moreover, major component manufacturing is supported by a mature supply chain and trained workforce and U.S.-flagged vessels hire a more domestic workforce. Port infrastructure is fully developed, and capable of supporting the industry.

Table 6. Components and Installation Infrastructure and Activities Estimated With Low- and High-Domestic Contents

	Domestic Content (%)	
Category	**Low**	**High**
Component Manufacturing and Supply Chain		
Nacelle/Drivetrain	0	50
Blades	25	75
Towers	25	75
Substructure and Foundation (Fixed Bottom)	25	75
Substructure and Foundation (Floating)	25	75
Electrical Infrastructure	25	75
Installation Activities		
Vessels	25	75
Ports and Staging	75	100
Engineering and Management	75	100
Operation and Maintenance	25/75	75/100

4.2 Jobs and Economic Impact Results

In the initial years between 2023 and 2030—the buildout supports an annual average of 31,300 jobs from construction and installation. Of these, 2,400 are on-site installation activities, whereas 29,000 are across the supply chain (Figure 11).[4,5]



(a) Construction jobs

(b) O&M jobs

Figure 11. Construction and O&M jobs

From 2031 to 2040, annual employment drops to an average of 16,000 jobs annually, with 1,400 on-site and 14,600 throughout the supply chain. Between 2041 and 2050, annual average jobs total 40,800: 3,600 on-site and 37,200 throughout the supply chain. Figure 11 shows the variability through time based on the modeled ReEDS capacity deployment, which, as noted previously, entails more interannual variability than might be expected.

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[4] The small number of on-site workers relative to supply chain is because of the narrow definition of "on-site" in the version of the Offshore Wind JEDI model used in this study. In this case, they are solely the workers physically present at the location of the wind turbines during the construction and O&M phases.

[5] Job estimates may not sum as a result of rounding.

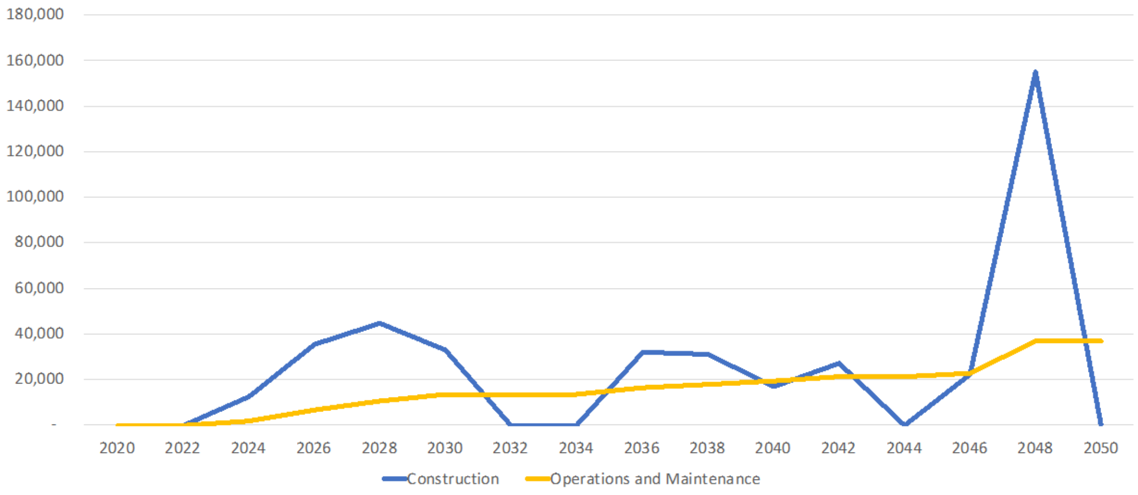

Figure 12. Number of construction (blue) and O&M (orange) jobs per year

O&M jobs are ongoing, so the total number of jobs in the final year of each period presented is more relevant than the annual average across those years. O&M jobs are assumed to exist for the duration of the life of the facility. In the event that a facility is rebuilt, they are assumed to exist for the life of the rebuilt facility.

By 2030, there are a total of 13,400 ongoing O&M workers, of whom 1,000 are on-site and 12,500 are throughout the supply chain. By 2040, this number increases to 19,400 (1,400 on-site and 18,000 supply chain) and by 2050 there are an estimated 36,700 jobs supported by O&M (2,600 on-site and 34,000 supply chain).[6]

Induced impacts are only related to offshore wind deployment scenarios as a result of worker expenditures, not the expenditures by the businesses themselves, and therefore are not included in the job totals shown elsewhere, including Figure 11 and Figure 12. However, as they are still a component of gross impacts, construction and installation activity would support an estimated 22,800 induced jobs from 2023 to 2030, 12,100 from 2031 to 2040, and 30,800 from 2041 to 2050. By 2030, O&M would support an estimated 9,800 induced positions, increasing to 14,200 by 2040 and 26,800 by 2050.

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[6] 2030 and 2050 numbers do not sum as a result of rounding.

4.2.1 Earnings per Worker

Table 7 shows average annual earnings per worker for construction and O&M activities. All of these earnings are at or above the U.S. average of $53,000 annually (Bureau of Labor Statistics 2020). The highest wages accrue as a result of construction and installation activities, with averages of $66,000 annually. The relatively smaller portion of on-site workers earns more than twice the wages earned by those throughout the supply chain on average. On-site O&M technicians similarly earn more than those supported throughout the supply chain, although by a lower proportion. Wages for induced jobs average $43,000 for the construction period and $39,000 in the O&M period. Wages for induced jobs average $43,000 for the construction period and $39,000 in the O&M period.

Table 7. Earnings per Worker for Construction and O&M Jobs

	Job Category	Average Annual Earnings
Construction	Installation activities	$132,000
	Support services, component manufacturing, and supply chain	$60,000
	Construction average	$66,000
O&M	Technicians and management	$79,000
	Support services and supply chain	$53,000
	O&M average	$55,000

Earnings generated by IMPLAN as well as the U.S. average are national and do not necessarily reflect prevailing wages in the specific regions in which wind power plants are constructed. National figures capture the greater supply chain across all states and average supply chain earnings reflect this detail. On-site earnings, however, are specific to regions in which plants are constructed. Higher wages can be expected in cities with higher costs of living in addition to simply being compensated more for specialized skills.

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